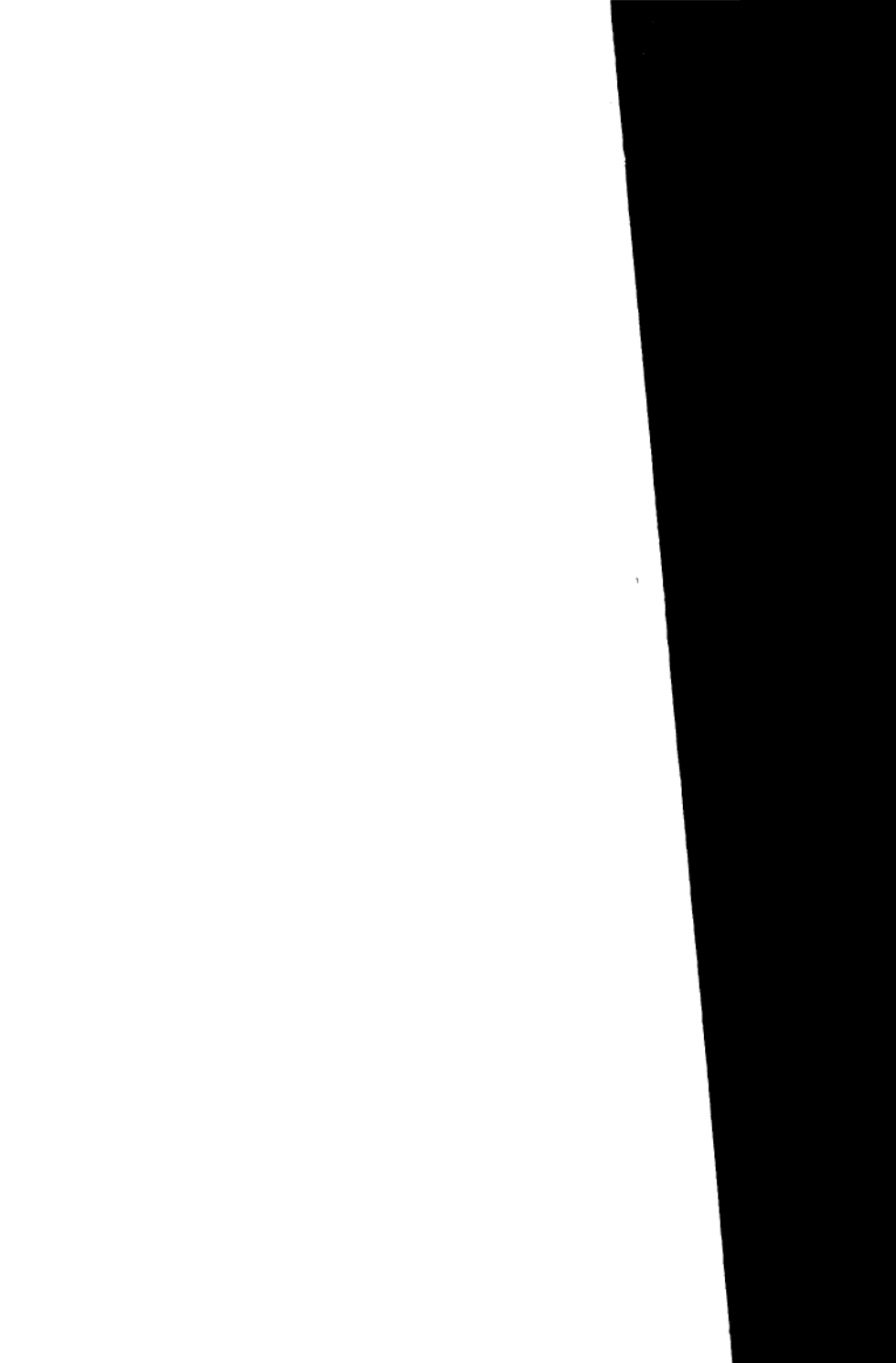


A stylized, high-contrast illustration. In the upper left, a grey silhouette of a nuclear reactor is visible. The background is a large, bright red, irregular shape. Overlaid on this is a white grid pattern representing a globe. In the lower right, a stylized plant with green leaves and red flowers grows upwards. The text is in white, bold, sans-serif capital letters.

NUCLEAR EXPLOSIONS—

A WORLD-WIDE HAZARD

A. M. KUZIN



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A WORLD-WIDE
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FOREWORD

At the present time when the peoples of the whole world are insistently demanding a halt to the arms race, a stop to the testing of atomic and hydrogen weapons and a ban on their use, it is very important that people everywhere know the truth about the danger that confronts mankind in the form of testing nuclear weapons and all the more so of their utilization in war.

An atomic war would bring with it incredible misery, but it can be averted if all people unite their efforts in the struggle for peace, if public opinion in all countries speaks out in a loud voice against nuclear warfare and for unconditional prohibition of atomic weapons.

Here, the weightiest word is that of the scientist, for he is better informed about all the terrifying consequences of nuclear blasts. Scientists throughout the world are deeply concerned over the effects of nuclear explosions on future generations and they are demanding the immediate conclusion of an agreement to discontinue nuclear weapons testing. This is evident from the statements of German, Japanese, French, British, Soviet and American scientists. In January 1958, the General Secretary of the United Nations Organization, Hammarskjöld, received a petition signed by 9,235 scientists from forty-four countries demanding cessation of nuclear bomb tests.

It is a well-known fact that the policy of the Soviet Government is straightforward and consistent on this issue:

a complete and unconditional stop to the testing of nuclear weapons.

From the foregoing it is obvious that Kuzin's book on the danger of nuclear explosions to mankind is a timely one. Kuzin is a prominent specialist in radiobiology, he has spent much time in the study of the action of radiation on the living organism and has participated in a number of international conferences that have discussed the dangers of nuclear warfare. This has enabled him to speak with authority. He has written for the layman about the present state of our knowledge concerning the great danger of nuclear explosions to the human race.

I am sure that this book will be of great interest to many and that it will contribute to the cause of peace.

Academician A. V. Topchiev

INTRODUCTION

All people, irrespective of the country in which they live, of their nationality, native language, political views, religion and convictions, must know the truth about the menace to mankind inherent in the explosions of atomic and hydrogen bombs. Everyone must know the danger of nuclear weapons testing—so-called experimental tests—and what it will be if atomic and hydrogen bombs are used militarily.

Everyone knows that the greatest attainment of the human mind—the discovery of ways to harness atomic energy—was first put into the building of an atomic bomb. And it is common knowledge that every year atomic bombs (and beginning with 1952, hydrogen bombs too) are regularly detonated in different parts of the globe.

All have heard of the devastating force of this new weapon. Common people throughout the world view with fear and wrathful protest the continuing stockpiling, in many countries, of this death-dealing weapon. Each atomic blast is one more step towards the horrors of nuclear warfare. Yet it is not universally understood what the actual extent of the danger is. There are still many who are unaware of the terrible consequences to human life even from the test shots that are now being fired, to say nothing of the incalculable misery that would engulf people everywhere on this planet if a nuclear war were unleashed, regardless of where the war began.

Many do not know that if an explosion occurs in the U.S.A., people suffer in Japan, India, Germany—in fact nearly everywhere on the globe.

Many do not know that if a burst is made today, its injurious effects on humans will be felt tomorrow, in a year's time, and tens of years hence.

Many do not know that if a person survives an atomic explosion, it does not in the least mean that his children and grandchildren will live and be healthy.

Many do not know how many lives are taken by every detonation of an atomic bomb, though the burst itself does not kill a single person.

But they *should* know. They should know this in order to raise their voices more firmly and insistently against nuclear testing, to unite their efforts in the struggle for complete prohibition of atomic weapons, for lasting peace on earth.

The aim of this book is to tell the reader in simple language what hazards atomic explosions are bringing to this and future generations.

I. ATOMIC ENERGY

For ages man has utilized the energy stored up in his natural environment. The mechanical energy of the winds has turned the millstones of windmills, and falling water has turned the turbines of hydropower stations. The flood of radiant energy from the sun is absorbed by the leaves of plants and converted into latent chemical energy in the products of vegetation. Petroleum, coal, wood and combustible gas have, locked up within them, enormous reserves of chemical energy which they release in combustion. Since time immemorial man has used the chemical energy of fuel to heat his dwelling and to prepare food. And this same energy moves locomotives, steamships and turbines. The chemical energy released in the combustion of liquid fuel is converted to mechanical energy and moves automobiles, airplanes and rockets. The possibility of transforming one kind of energy into another is widely used to obtain electricity, which is conveniently transmitted over long distances; it lights cities and villages, moves electric trains, trams and trolley-buses, and it turns the shafts of electric motors that move the machines of industry.

By 1939 our knowledge of the structure of the atom, of the nature of radioactivity, of such elementary particles as nucleons, and of the interaction of mass and energy and their interconversion had reached a high level. Simultaneously, a number of scientists put forth well-founded

hypotheses on the possibility of releasing the new inexhaustible sources of energy locked up in atomic nuclei.

Underlying these conjectures was the principle of the equivalence of matter and energy that Albert Einstein had advanced as early as 1905. From Einstein's equation

$$E=mc^2,$$

which relates the energy E , the mass of matter m and the speed of light c , it followed that a relatively small mass of substance contains enormous quantities of energy, because the velocity of light is very large.

If one kilogramme of matter could be converted into energy *in toto* it would yield 25,000,000,000 kilowatt-hours of power. To get some idea of this colossal figure, recall that the entire electrical output in the U.S.A. in 1939 during one month was only half this amount.

Before, man could utilize only the chemical energy of matter. In chemical reactions the masses, before and after, remain practically the same due to the law of conservation of mass that holds in chemistry. The quantity of energy obtained in chemical transformations is considerably less than in nuclear transformations, which perceptibly affect the mass of a substance. The energy produced in the burning of one kilogramme of coal amounts to 8.5 kilowatt-hours. Compare these two numbers: 25,000,000,000 and 8.5. It is obvious that the solution of this problem—energy obtained from mass, that is, in nuclear reactions—offers great promise. This is why tireless efforts were made by physicists in the U.S.A., Germany, the Soviet Union, Britain and other countries to resolve it.

Energy-wise, the best atomic-power producers are the heavy atoms of uranium. In nature, nearly all the elements are in the form of assemblies of atoms that have practically identical chemical properties, but differ slightly as to mass. These different species of any one element are called isotopes. Uranium, too, has several isotopes. The most common uranium isotope in the natural ores is ura-

nium of atomic weight 238 (99.28%). Then there is uranium-235 (atomic weight: 235) which makes up only 0.71 per cent of natural uranium, and, finally, we have an insignificant quantity (0.005 per cent) of uranium-234.

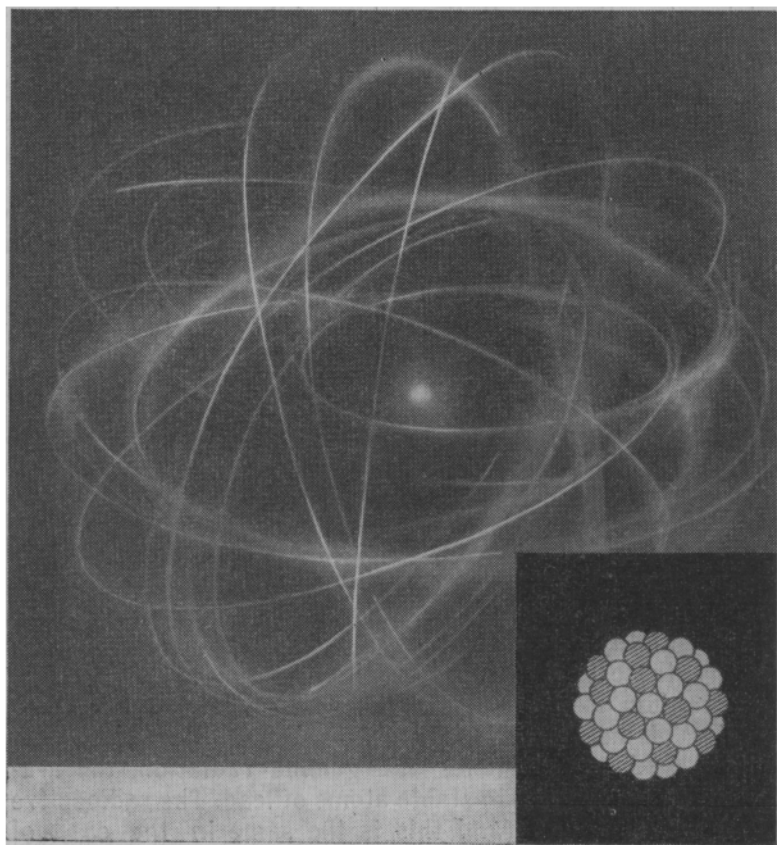


Fig. 1. The structure of the atom and the atomic nucleus.

The structure of the uranium atom is highly complex. Like the atoms of all other elements, the uranium atom consists of a central nucleus and an outer cloud of elec-

trons. The nucleus occupies but a tiny volume of the whole atom, yet constitutes nearly its entire mass. The electrons form something in the nature of an outer shell. They move round the nucleus with enormous velocities and at a considerable distance. This electron cloud is what actually determines the overall dimensions of the atom, as is shown schematically in Fig. 1.

The electron cloud of the uranium atom consists of 92 electrons. They are kept within the atom by the attraction of 92 protons in the nucleus, which in addition contains neutrons. The different isotopes of uranium contain different numbers of neutrons. The nucleus of uranium-238 has 146 neutrons, uranium-235 has 143 neutrons. Atomic nuclei that have big surpluses of neutrons over protons are unstable, liable to break up. Such unstable nuclei disintegrate spontaneously, ejecting various particles as they convert to a stable state.

The decay rate is characterized by the half-life period, that is the time during which one half of all the atoms disintegrates (decays). Decay may occur in two ways: with the emission of electrons (or positrons)—this is known as beta-decay—or by the ejection of alpha particles which consist of two neutrons and two protons: this is called alpha-decay. The transition of a nucleus from an unstable state to a stable state is accompanied by short-wave, highly penetrating rays—gamma radiation. Collectively, these phenomena are called radioactivity.

Uranium is a typical radioactive substance. After a series of disintegrations accompanied by the ejection of alpha and beta particles and gamma radiation, the uranium atoms convert to stable atoms of lead. The radioactive decay of uranium (and this is the same in the case of other radioactive elements such as radium, thorium, etc.) is accompanied by the release of substantial quantities of energy. However, as a source of power, natural radioactive decay doesn't have anything to offer. The process is slow and there is no way to accelerate it. Uranium-238 has a

half-life of 4,498,000,000 years. It is therefore obvious that no matter how much energy is released, the amount produced in any foreseeable future would be infinitesimal.

The attention of scientists was attracted to a different phenomenon. The observations of O. Hahn and F. Strass-

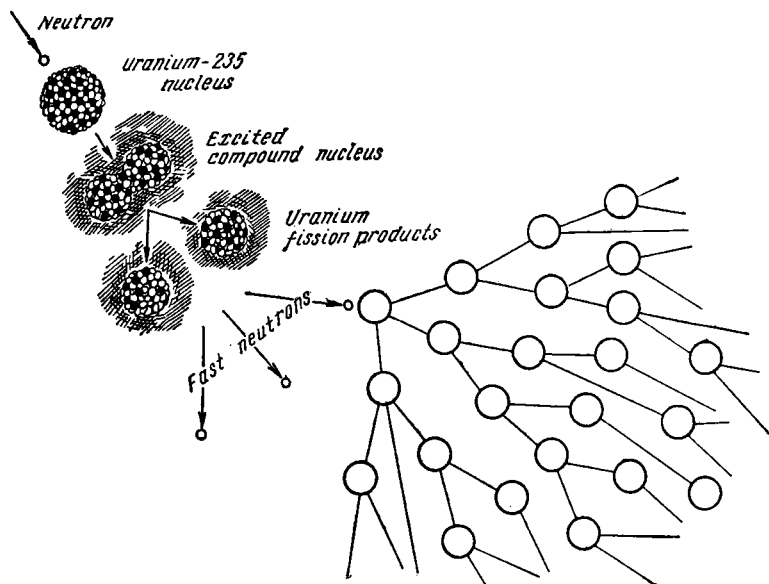


Fig. 2. How a fission chain reaction develops.

mann in Germany, O. Frisch in Denmark, E. Fermi in the U.S.A., F. Joliot in France and others showed that when uranium is bombarded with neutrons, one of the latter may be captured by the nucleus. The resulting nucleus becomes unstable and quickly breaks into two parts. This splitting, which became known as fission, is accompanied by a loss of mass, and, consequently, by the release of a large quantity of energy. Probably the most interesting point is that during the fission of the uranium nucleus two

or three neutrons are ejected. If these two or three neutrons were in turn captured by uranium nuclei, another two or three nuclei would break up and release some 4 to 9 neutrons, which would split 4 to 9 atoms, resulting in 8 to 27 neutrons. The number of atoms undergoing fission would thus rapidly increase. The resulting chain reaction would, if given enough uranium, lead to a fast disintegration of all the atoms, that is, to an atomic explosion. This was how the idea of an atomic bomb was born. Diagrammatically, it is shown in Fig. 2.

If it were possible to regulate the neutron flux, the explosion could be averted and the reaction would proceed at a definite rate with the release of fission energy that could be put to use. This would be an atomic reactor producing atomic energy for peaceful uses.

By 1940 these two lines of solving the problem were finally clarified, but there was still quite some distance to their practical realization.

Only uranium-235 proved amenable to a chain reaction. But natural uranium contains no more than a tiny fraction of it—0.7 per cent. The problem, therefore, was to isolate it, increase the proportion of it, or, in technical parlance, to enrich the uranium.

The reaction of a neutron and uranium-238 was also of great interest. Although the resulting uranium-239 did not fission, it emitted electrons and converted, via neptunium, to plutonium—Pu²³⁹. This new transuranium element was now fissionable with thermal neutrons. Thus, the abundant uranium-238 became a valuable raw material for the production of a fissile material—plutonium.

Then the Second World War began. From 1940, all research in nuclear fission became secret. Work went on in isolation in the U.S.S.R., Germany and the U.S.A. In the United States, investigations were conducted jointly with Canada and Britain.

The efforts of scientists in the U.S.A. were focused on the making of an atomic bomb. On July 16, 1945, a desert

area in New Mexico saw the first test explosion of an atomic bomb, and in August 1945, when the outcome of the war with Japan was already clear, the United States carried out a vandalic experiment by throwing two atomic bombs on the peaceful Japanese cities of Hiroshima and Nagasaki.

Soon afterwards the U.S.S.R. completed its own atomic bomb.

Atomic energy was first harnessed for peace in June 1954 when the Soviet Union put into operation the first nuclear power station in the world.

At the same time, work was progressing with another nuclear reaction—the fusion reaction. If a proton, that is, a hydrogen nucleus, is fused with a nucleus of tritium (a heavy hydrogen isotope), a helium nucleus will form with a reduction in mass that will release a tremendous amount of energy. Reactions of this type, called thermonuclear reactions, are apparently constantly occurring in the sun, serving as the source of solar energy.

The difficult thing in reactions of this kind is to overcome the forces of repulsion between the nuclei of hydrogen and tritium, and this requires imparting to these particles colossal energy. We know that many chemical reactions do not proceed at ordinary temperatures and require thermal activization of the molecules to get started. To take an example, a tree can lie in the air an indefinitely long time without any reaction taking place. But if at some spot we impart to the wood molecules sufficient energy by heating them, that is, if we simply set fire to the tree, a reaction will begin with the oxygen of the air, and the wood will burn. Since such a reaction releases heat all the time, the fire will spread until all the wood has burnt up.

Something very similar occurs in the mixture of hydrogen and tritium. At ordinary temperatures there is no reaction. And just a little heating won't help either. To overcome the repulsive forces of the nuclei one needs a tem-

perature of several million degrees. This only the atomic bomb could produce. The explosion of such a bomb yields a temperature high enough to "ignite" a mixture of hydrogen and tritium and thus set off a thermonuclear reaction.

This was the principle that underlay the hydrogen bomb.

Let us now examine in more detail what happens when these new weapons explode.

II. THE ATOM BOMB

We have seen the possibility of a fission chain reaction developing in such substances as uranium-235 or plutonium-239. This chain reaction can be triggered by a single neutron. However, certain specific conditions are needed for an explosion to occur as a result of the established

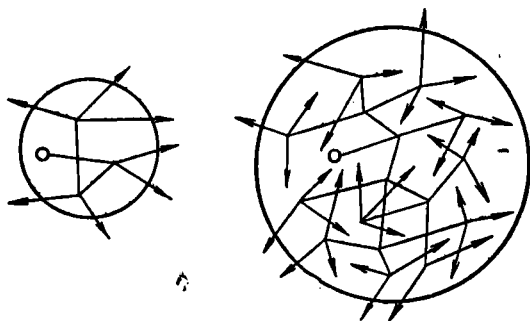


Fig. 3. Why the mass must be "critical" for an explosion to occur.

chain reaction. Firstly, the explosive material must consist of sufficiently purified uranium-235 or plutonium-239. If other, impurity, atoms are present, the neutrons produced in fission may be captured by them and the chain reaction will fizzle out. Secondly, a very essential condition is the volume of the explosive. If the amount of

uranium-235 is small, the neutrons produced in the chain reaction will escape as shown in Fig 3; no "avalanche" will build up and there will not be any explosion. Thus, a bomb requires a mass of fissile material such that the loss of neutrons is insignificant.

This minimum mass required to produce an explosion is called the critical mass. In the case of uranium-235 it comes out to roughly one kilogramme. Therefore, because of the criticality of the mass it is impossible to build an atom bomb of small destructive force.

There are always some stray neutrons in the air. And so nuclear explosives cannot be kept in quantities equal to or exceeding the critical mass, otherwise they would explode spontaneously. Usually, the nuclear fuel (uranium-235 or plutonium-239) of an atomic bomb is in the form of several pieces, each of which is less than the critical mass. To explode, they have to be brought together very rapidly. Then the chain reaction sets in and 2, 4, 8, 16, 32, 64, etc., neutrons are generated. After 80 successive fissions the number of neutrons is sufficient to "split" all the nuclei in one kilogramme of uranium. All this takes place in a time equal to one millionth part of a second.

The fission of all the atoms in one kilogramme of uranium-235 releases a stupendous quantity of energy—roughly equal to that produced in the detonation of 20,000 tons of TNT, which is one of the most powerful explosives. (Rarely more than one ton of TNT is used in conventional bombs.)

The release of so much energy in so small a space results in a temperature, at the instant of burst, measured in millions of degrees. The fission products, and the bomb shell as well, are vaporized instantly. The formation of a large mass of gaseous matter in a small space and in microseconds (millionths of a second) gives rise to an enormous pressure. This is how the shock wave originates that produces physical damage. An atomic bomb burst

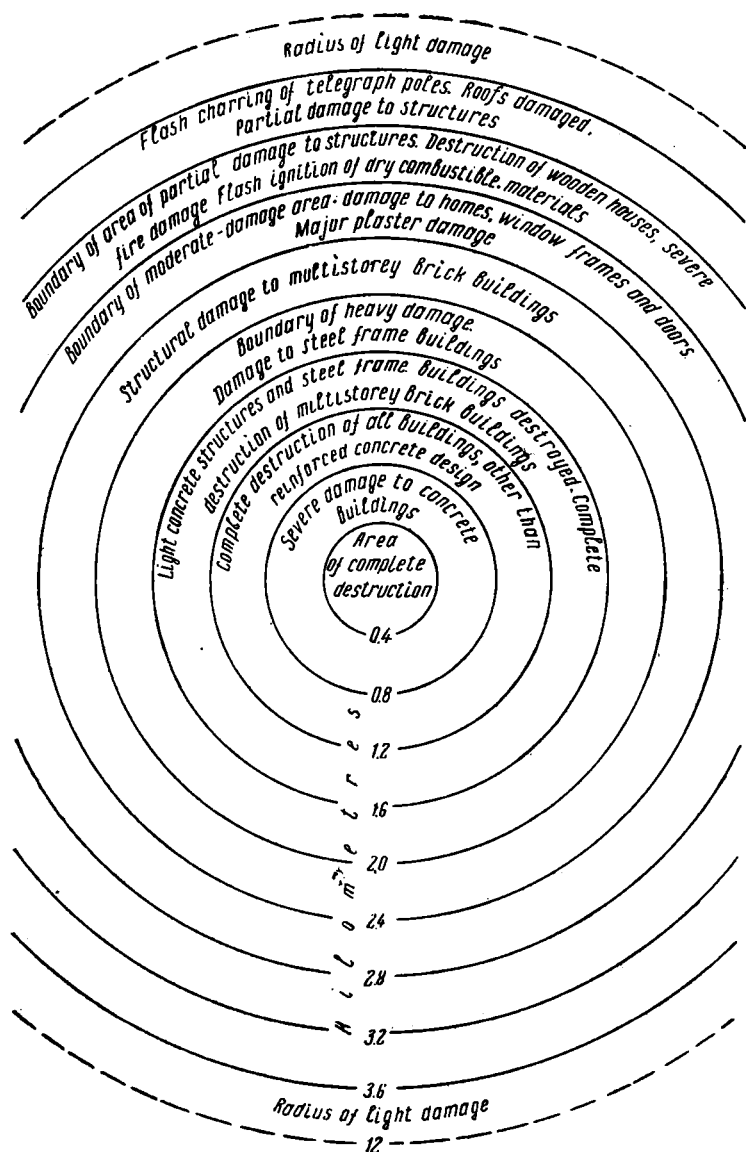


Fig. 4. The destructive range of a nominal atomic bomb.

also produces a brilliant flash of light that burns and melts all objects near the point of explosion.

The force of the shock wave, the explosive temperature and intensity of the flash in the explosion of the smallest size atomic bomb (nominal A-bomb) exceed those that occur in the burst of the most powerful TNT bomb by a factor of over 1,000. In addition, the blast of a nuclear bomb gives rise to two fundamentally new phenomena: strong radioactive emission and radioactive uranium fission products. Long after the burst, these products continue to emit radiations that are injurious to living organisms.

Nearly 80 per cent of all the energy released is converted into the kinetic energy of the fission products and takes the form of a shock wave, thermal radiation and a blinding flash of visible radiation. Some six per cent is taken up by the radioactive emission during the explosion. And about half of this amount is in the form of neutron emission, which is capable of making all irradiated objects radioactive.

The remaining energy (roughly 14 per cent) is carried away by the fission products and is emitted for a long time after the burst in the form of radioactive radiations.

In an air burst, the shock wave of a nominal atomic bomb (of the type dropped on Hiroshima and Nagasaki) affects an area of radius 8 to 12 kilometres [1]. The destructive force of the shock wave falls off with increasing distance from the point of the explosion. Fig. 4 gives a diagrammatic representation of the damage produced by such a bomb.

Very important is the terrain. Many of the buildings protected by favourable terrain may remain intact even close to the burst, while the very same type of buildings not protected in this way will be destroyed out to far greater distances. This is evident from the Hiroshima and Nagasaki bombings. The town of Hiroshima had 75,000 houses. Seven thousand were destroyed completely by the

atomic blast and another 55,000 were wiped out by fire. Result: 90 per cent of all dwellings destroyed. Thanks to favourable local terrain, many more structures remained intact after the Nagasaki explosion, though the bomb was more powerful and increased the radius of damage by 15 per cent.

The difference is particularly striking when we compare the number of casualties in the Hiroshima and Nagasaki bombings [2]:

	Hiroshima	Nagasaki
Dead	78,150	23,753
Missing	13,983	1,924
Injured	37,424	23,345
Otherwise afflicted	235,656	89,025
<i>Total . .</i>	<i>365,213</i>	<i>138,047</i>

These figures show that Nagasaki had one-third as many casualties though the population density was nearly twice that in Hiroshima.

The high temperature of the explosion and the high intensity of the heat flash cause numerous skin burns.

Instantaneous burns produced by the thermal radiation are observed out to three kilometres from ground zero (the point on the surface of the earth directly below the explosion). The thermal radiation lasts 2 to 3 seconds and affects any surface open to the explosion. Besides producing burns, it chars and ignites combustible materials.

In this respect, conventional bombs are no different, though the scale is much smaller.

It has already been mentioned that the essential difference lies in the presence of radioactive radiations. The explosion gives rise to a very powerful flux of neutrons accompanied by gamma rays (the alpha and beta rays that likewise appear are absorbed by the atmosphere and do not reach the earth's surface in an air burst).

Whole-body gamma radiation is exceedingly dangerous. It is very hard to protect oneself from gamma rays be-

cause they penetrate wood, brick and other materials with ease. Only relatively thick layers of earth or concrete (from 0.5 to 3 metres, depending on the radiation intensity) can offer protection against these rays. The gamma-ray intensity falls off in inverse proportion to the square

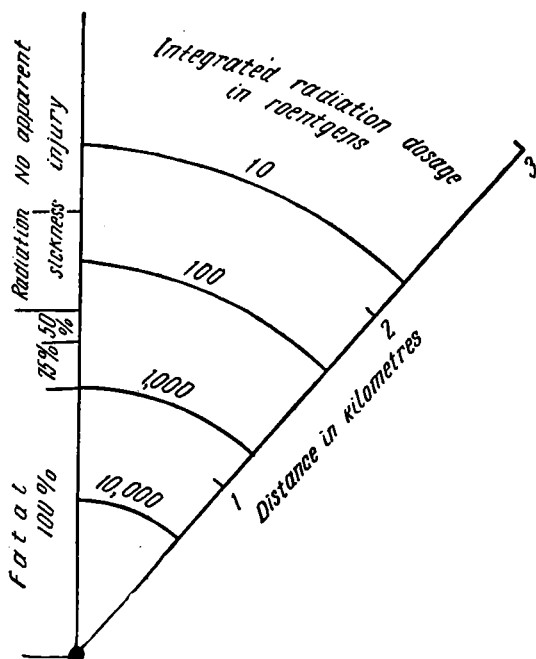


Fig. 5. The effects of gamma radiation at various distances from the explosion site of a nominal atomic bomb.

of the distance, and at roughly two kilometres from the point of explosion they are harmless in the case of small bombs of the Nagasaki type. The action of gamma rays as a function of distance is shown in Fig. 5.

No less dangerous is the neutron emission produced at the instant of the explosion. Within one kilometre the neutron dose is lethal. Upon contact with the ground, the

neutrons are captured by various elements, which become radioactive. For example, neutron irradiation of silicon produces radioactive silicon-31, of aluminium, radioactive aluminium-28, of sodium, radioactive sodium-24, etc. Other elements, including phosphorus and iron, also become radioactive. All this results in a substantial increase in the radioactivity of irradiated portions of the ground following an explosion. Foodstuffs that have undergone neutron irradiation will become radioactive and, hence, totally unusable until the activity has completely disappeared (decayed). True, this so-called induced activity decays rather quickly and represents a serious hazard only during the first few days and, especially, the first few hours following the explosion.

Such are the effects of an atom bomb in the immediate vicinity of the explosion. An increase in the weight of the nuclear fuel will produce more blast and will expand the radius of damage and radiation effects. However, this expansion is not directly proportional to the weight increase of the nuclear fuel. Apparently, this is the reason why it is not so expedient to use very much larger nuclear bombs.

So far we have said nothing about what happens to the radioactive fission products produced in an atomic burst. It is precisely these products that spread the hazard hundreds and thousands of kilometres from the site of explosion. This will be dealt with in a separate chapter.

We must now say a few words about the difference between the explosion of a fission bomb (the atomic bomb described above), a fusion bomb (commonly called a hydrogen bomb) and a fission-fusion-fission bomb (a combination atom-hydrogen bomb).

III. THE HYDROGEN BOMB

As has been pointed out, the hydrogen bomb is based on an entirely different nuclear reaction. The atomic bomb explosion is produced by a chain reaction in the fission of

heavy uranium and plutonium nuclei, whereas the hydrogen bomb gets its energy from a reaction between the nuclei of light elements. Most interesting in this respect are the nuclei of hydrogen isotopes. Structurally, the hydrogen atom is the most simple: one atomic electron circling a nucleus made up of a single proton (Fig. 6).

At present, three hydrogen isotopes—hydrogen (H_1^1), deuterium (H_1^2) and tritium (H_1^3)—are known. In Fig. 6 we see that the only difference between deuterium and or-

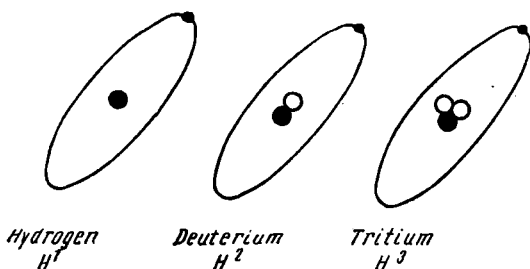
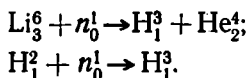


Fig. 6. The structure of the hydrogen isotopes.

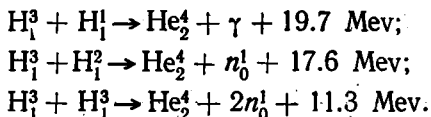
inary hydrogen is the extra neutron in the nucleus. This makes the deuterium atom twice as heavy as ordinary hydrogen; hence the name "heavy hydrogen." But the chemical properties of these isotopes are identical. Just as hydrogen readily combines with oxygen to form H_2O —water—so deuterium combines with oxygen yielding deuterium oxide D_2O , or heavy water. Ordinary water contains about one hundredth of a per cent of heavy water. If water is decomposed by electrolysis, the ordinary part (light water) will decompose first, leaving a residue enriched in heavy water. In this way it is possible to obtain pure heavy water and, thus, heavy hydrogen—deuterium. Deuterium is very expensive due to the enormous amounts of electricity required in the hydrolysis of water to obtain relatively small quantities of pure deuterium.

The third hydrogen isotope is tritium, which was obtained artificially by irradiating lithium or deuterium with neutrons:

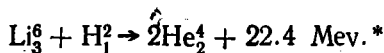


Tritium is now obtained in nuclear reactors (which produce powerful fluxes of neutrons) by means of reactions similar to those given above.

But to return to the hydrogen bomb. What reaction supplies the stupendous destructive energy of the hydrogen bomb? The fission bomb utilizes the energy produced in the fission of heavy nuclei, while the hydrogen bomb exploits the energy released in the synthesis of a helium nucleus from the nuclei of hydrogen—deuterium or tritium—which are lighter. Three reactions of this type are given below (the energy released is in Mev—million electron-volts):



Another interesting reaction is that between deuterium and lithium:



It will be seen that all these reactions release enormous quantities of energy—of the order of 11 to 22 million electron-volts.

* H_1^3 is tritium, H_1^1 —hydrogen, H_1^2 —deuterium,

He_2^4 —helium of mass four, n_0^1 —a neutron,

γ —a gamma photon, and Li_3^6 —lithium of mass six.

Consequently, if a sufficient amount of tritium and deuterium is put into a strong bomb shell and a fusion reaction initiated, this reaction will instantaneously release a colossal amount of energy that will produce an explosion of horrific force. The problem is to initiate the nuclear reaction. We know that atomic nuclei exhibit mutual repulsion and that it is difficult to bring them into close enough contact for a reaction to set in. What is needed to overcome the energy barriers of nuclear reactions is, as I have already pointed out, a temperature of a million degrees. Until recently, no such temperatures had ever occurred on the earth; only astrophysicists studying processes in the sun and stars spoke of their existence. A one-million-degree temperature was first obtained in the explosion of an atom bomb.

Here, then, was a "fuse" for a hydrogen bomb. In the hydrogen bomb, the "fuse," or initiator of the reaction, is nuclear fuel—uranium-235 or plutonium-239; in addition, it contains two hydrogen isotopes, deuterium and tritium. The reaction begins by isolated masses of uranium or plutonium coming together and forming a super-critical mass, which initiates the atomic explosion. At this instant the temperature reaches a million degrees and more and triggers the second reaction between the nuclei of tritium and deuterium. This thermonuclear reaction releases an energy hundreds of thousands of times greater than the first, producing the explosive force of the hydrogen bomb.

The destructive power of the hydrogen bomb at the point of explosion is due to the same factors that operate in an atomic bomb burst. We find the same shock wave, thermal radiation and powerful radioactive emission, the latter mostly from neutrons. The hydrogen bomb differs from the atom bomb chiefly in the quantitative effect that it produces.

The following comparison [3] gives a vivid idea of the colossal destructive power liberated in the burst of a hydrogen bomb.

Type of Bomb	Explosive energy in TNT tons equivalent
TNT bombs used in World War II	2 to 3
Atomic bomb dropped on Nagasaki	20,000
Weight of all bombs dropped on Germany during World War II	1,300,000
Total weight of explosives consumed during World War II	5,000,000
Hydrogen bomb detonated by U.S.A. at Bikini Atoll in 1954	15,000,000

If, in addition, we take the total explosive energy released in World War II to be greater than that released in all the earlier wars including World War I, it will be seen that the test explosion of a single hydrogen bomb like the one set off in the U.S.S.R. in November 1955 or in the U.S.A. in May 1956 liberates far more energy than the total explosive energy released by mankind in all its history.

The hydrogen (fusion) bomb produces a thousand times more energy than an atomic (fission) bomb, and the damage caused by the shock wave covers an area roughly tens times greater. What this means is that while a fission bomb causes severe damage within a radius of three kilometres, a fusion bomb extends this to nine kilometres. A particularly big increase is seen in the area of thermal-radiation damage—in this case it affects an area thirty times that of a fission bomb, which is to say that 16 kilometres from the site of explosion the thermal rays can char wood and even ignite it. The temperature at the point of explosion of a hydrogen bomb is so high that it is capable not only of melting but of vaporizing all metals and minerals in the vicinity. This is why in a near-ground burst of a hydrogen bomb an enormous quantity of ground dirt is mixed with the radioactive nuclear-reaction products forming material for radioactive fall-out, which is particularly abundant after such detonations.

According to the data of American authors [4], the explosion of a 20 megaton bomb* would destroy completely all ordinary buildings over an area of 200 square kilometres. The zone of severe damage would be 500 sq. km., and that of partial damage would extend to some 2,580 sq. km. If we realize that such cities as Paris, London, Chicago and Berlin occupy areas of 104, 300, 550, and 888 sq. km.

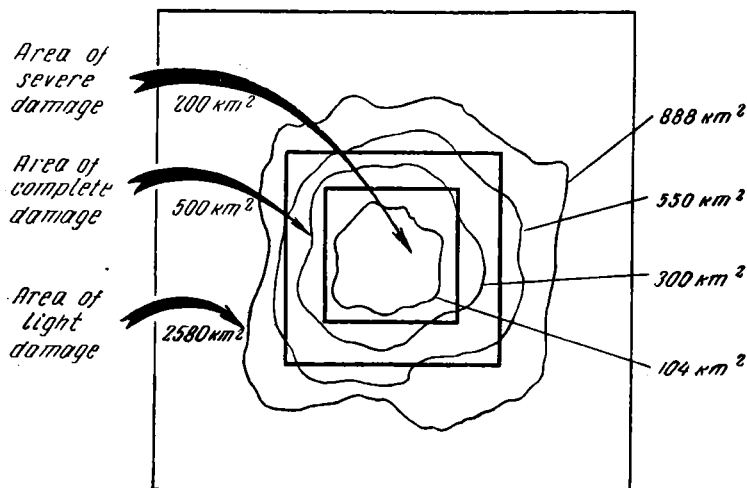


Fig. 7. Area destroyed by the explosion of a 20-megaton bomb (in sq. km.).

respectively, it will be clear that a single such bomb would suffice to wipe out the greatest centres of civilization, the heart of human culture. This comparison is graphically given in Fig. 7.

* A megaton bomb is one that releases an energy equivalent to millions (mega) of tons of TNT. Hereafter, all calculations will be given on the basis of a 20-megaton bomb (equivalent to 20,000,000 tons of TNT explosive energy). The energy released by such a bomb is equal to 8.4×10^{23} ergs, or 2×10^{16} gramme calories, or 2.3×10^{10} kilowatt-hours. A megaton nuclear bomb produces something like 6×10^{27} neutrons (equivalent to a mass of ten kilogrammes) and about 19 kg. of radioactive strontium-90 of total activity 2.8×10^6 curies.

There is also a sharp increase in the area affected by the initial radiation and thermal rays (the latter produce skin burns). Fig. 8 gives some idea of the radius of action of such bombs [3].

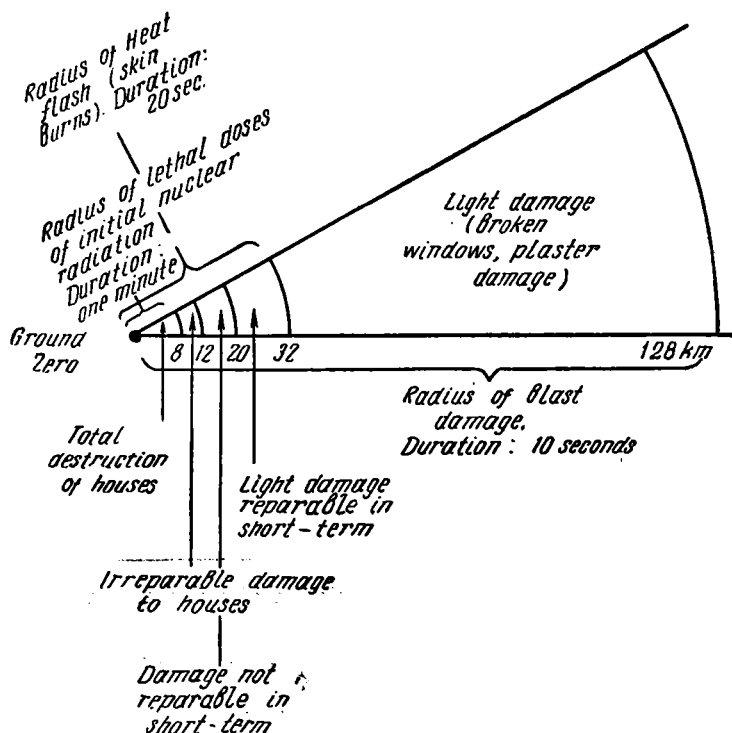


Fig. 8. Damage inflicted by the burst of a 20-megaton hydrogen bomb (air burst at a height of about 2.4 km=1.5 miles) [3].

A distinguishing feature of the hydrogen bomb is the very powerful flux of neutron radiation at the instant of explosion. These neutrons interact with the nuclei of surrounding atoms and impart to ordinary substances radioactivity. The result is induced radioactivity. On the

other hand, there are fewer radioactive fission products than in a fission bomb of equivalent strength. The fission products come from the fission explosion that serves as the "fuse" to initiate the thermonuclear reaction. Their quantity will be just the same as in the burst of a nominal atomic bomb. U.S. government circles have been talking a lot about a "clean" bomb, that is, a hydrogen bomb which explodes producing hardly any radioactive fall-out. For instance the large number of shots fired by the U.S.A. in 1958 over the protests of the peoples of the world were announced as tests of "clean" bombs. There is of course nothing that can justify these tests, directed as they are towards the making of a new weapon of mass extermination that will bring to people only death and distress. N. S. Khrushchov very pointedly remarked that there cannot be a clean bomb if the job it does is dirty. But this is not all. The talk about its "cleanliness" is only to disorient public opinion. The detonation of an all-fusion (pure hydrogen) bomb yields radioactive fission products from the fission "fuse" and, in addition, large quantities of radioactive substances produced by the very powerful and inevitable neutron emission.

Direct observations carried out by the Soviet research vessel *Vityaz* in the vicinity of the Philippine Islands during the United States tests in the Pacific Ocean showed that these so-called clean bombs produce a great deal of radioactive fall-out.

Finally, there is yet another type of nuclear bomb, which was apparently tested by the Americans in the famous March 1, 1954 test shot at Bikini Atoll. The explosion was equivalent to 15,000,000 tons of TNT, and was officially reported as a hydrogen bomb test. However, it gave rise to exceedingly large quantities of radioactive fall-out, in fact much more than could be produced in a thermonuclear reaction. An analysis of the fall-out by Japanese scientists [6] showed the presence of the fission products of uranium, and also the short-lived uranium isotope, uranium-237.

This suggested to a number of atomic scientists [7] that the bomb contained uranium-238 as the principal explosive substance, while the thermonuclear reaction was only a trigger mechanism for the fission process.

It will be recalled that natural uranium-238 is not fissionable by slow neutrons. And so the fission (atomic)

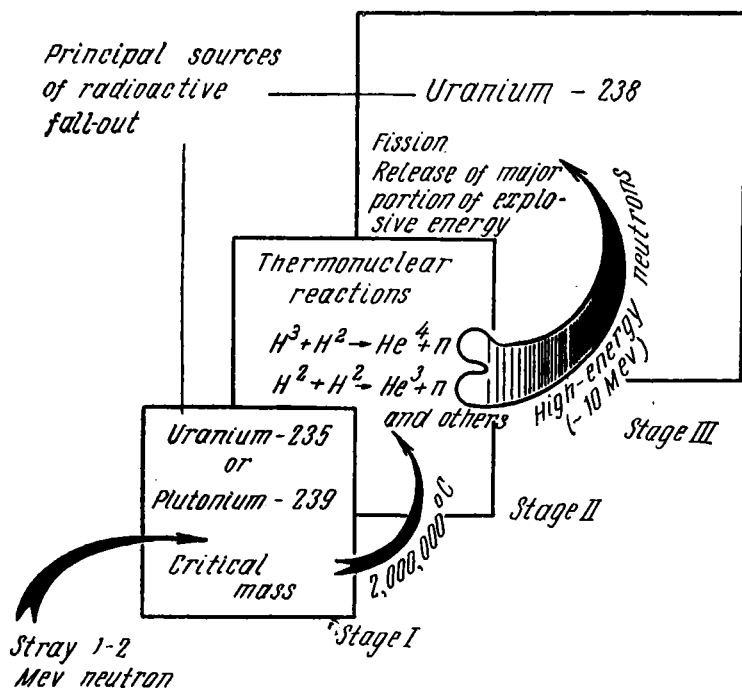


Fig. 9. A three-stage fission-fusion-fission bomb with natural uranium-238 (schematic).

bomb required the expensive uranium-235 or the reactor-produced plutonium-239. But it turned out that the abundant uranium-238 isotope undergoes fission if the neutrons have a high enough energy (some 10 Mev). A thermonuclear reaction produces such neutrons. This brings us

to the following possible bomb scheme: a megaton fission-fusion-fission bomb (something in the nature of a mixed atom-hydrogen bomb). The first stage is the explosion of a nominal fission bomb with uranium-235 or plutonium-239, which produces a temperature high enough to initiate the thermonuclear (fusion) reaction; the second stage is a tritium-deuterium fusion reaction. The fusion reaction yields ultra-hard neutrons that trigger the third stage—a fission reaction of the relatively cheap natural uranium-238, which makes up the bulk of the combination nuclear bomb equivalent to 20,000,000 tons of TNT explosive energy (Fig. 9).

Calculations [3] show that a bomb of this type is hundreds of times cheaper than the equivalent yield of an all-fusion bomb (that is, one due mainly to a thermonuclear reaction). This, apparently, was what determined the type of bomb for the Bikini tests and it is also the reason for the unusually large quantities of radioactive fall-out from which the Japanese island dwellers suffered so much.

It has been calculated that in the detonation of a 20-megaton fission-fusion-fission bomb the radioactivity of the fission products at the end of the first minute after the explosion is equal to the enormous amount of 8.2×10^{14} curies (one curie is roughly the activity of one gramme of radium). This is activity on the order of a hundred thousand million kilogrammes of radium.

If we consider that the shock wave and thermal radiation are operative during the first 10 to 20 seconds following the explosion, it will be clear that in subsequent tens of seconds every living thing that has survived within a radius of 8 to 10 km. from ground zero will be exposed to enormous, unquestionably lethal, doses of radiation.

The radioactivity of the fission products falls off rapidly, mainly due to the decay of the short-lived isotopes. Some idea of the rate of decrease in radioactivity of the fission products may be had from the following table,

which gives the radioactivity of the fission products of a 20-megaton nuclear bomb as a function of time [3].

Time after detonation	Activity (curies)
At end of 1 minute	8.2×10^{14}
At end of 1 hour	6.0×10^{12}
At end of 1 day	1.3×10^{11}
At end of 1 month	2.3×10^9
At end of 1 year	1.1×10^8
At end of 10 years	8×10^6

From this table it is clear that despite this rapid decrease, there will still be 8,000,000 curies of radioactivity even after a time of 10 years. This activity is due mostly to the long-lived fission products (strontium-90, cesium-137 and others) which by this time will have dispersed over the entire surface of the earth causing an increase in the natural radioactive background of this planet.

IV. RADIOACTIVE FALL-OUT

The explosion of fission and fusion bombs produces large quantities of radioactive material. First of all, the explosion results from the fission of uranium-235 or plutonium-239-nuclei. The nucleus of uranium or plutonium captures a neutron, becomes unstable and then breaks into two nearly equal pieces. However, these pieces are never exactly equal: one is always a bit smaller, the other a bit larger. Since the fission can occur in different ways (there are about 40 possibilities), the atomic numbers of the large quantities of radioactive fission products produced range from 30 to 63. A total of some hundred different isotopes emerge with very different half-lives—from seconds to years.

Table 1 is a list of the more important isotopes that make up the bulk of the fission products.

Due to the high temperature of the explosion, all these radioactive isotopes are in a gaseous state in the fireball

Table

**The Principal Isotopes Produced in the Fission of Uranium-235
and Plutonium-239**

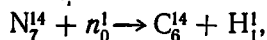
Atomic number	Element	Atomic weight and chemical symbol of isotope	Type of radiation	Half-life
36	Krypton	Kr ⁹⁵	β, γ	10 years
37	Rubidium	Rb ⁸⁷	β	6.1 × 10 ¹⁰ years
38	Strontium	Sr ⁸⁹	β	54 days
	Strontium	Sr ⁹⁰	β	28 years
	Strontium	Sr ⁹¹	β, γ	10 hours
	Strontium	Sr ⁹²	β	2.7 hours
39	Yttrium	Y ⁹¹	β	61 days
	Yttrium	Y ⁹⁴	β, γ	16 minutes
40	Zirconium	Zr ⁹⁵	β, γ	65 days
	Zirconium	Zr ⁹⁷	β, γ	17 hours
42	Molybdenum	Mo ⁹⁹	β, γ	2.8 days
44	Ruthenium	Ru ¹⁰³	β, γ	40 days
	Ruthenium	Ru ¹⁰⁶	β	290 days
48	Cadmium	Cd ¹¹⁵	β, γ	43 days
51	Antimony	Sb ¹²⁶	β	28 days
52	Tellurium	Te ¹²⁷	β	90 days
	Tellurium	Te ¹³²	β, γ	3.2 days
53	Iodine	I ¹³¹	β, γ	8.1 days
	Iodine	I ¹³³	β, γ	21 hours
	Iodine	I ¹³⁴	β, γ	52 minutes
	Iodine	I ¹³⁵	β, γ	6.6 hours
54	Xenon	Xe ¹³⁵	γ, e ⁻	15 minutes
55	Cesium	Cs ¹³⁷	β, γ	33 years
56	Barium	Ba ¹³⁹	β, γ	1.4 hours
	Barium	Ba ¹⁴⁰	β, γ	13 days
	Barium	Ba ¹⁴¹	β, γ	18 minutes
57	Lanthanum	La ¹⁴³	β	15 minutes
58	Cerium	Ce ¹⁴¹	β, γ	33 days
	Cerium	Ce ¹⁴³	β, γ	1.5 days
	Cerium	Ce ¹⁴⁴	β, γ	282 days
59	Praseodymium	Pr ¹⁴⁴	β, γ	17 minutes
60	Neodymium	Nd ¹⁴⁷	β, γ	12 days
61	Promethium	Pm ¹⁴⁷	β	2.2 years
62	Samarium	Sm ¹⁵⁵	β, γ	123 minutes
63	Europium	Eu ¹⁵⁵	β, γ	1.7 years

and, with the latter, rapidly ascend into the upper layers of the atmosphere. If the shot is fired near the earth's surface, a large amount of ground dirt will be sucked up into the fireball. And, due to the very strong neutron ra-

diation at the instant of the explosion, many of the soil elements also become radioactive isotopes. Silicon—the main constituent of sand—produces silicon-31 with a half-life of 2.6 hours; aluminium—a constituent of clay—can produce a short-lived magnesium isotope (magnesium-27) with a half-life of 9.3 minutes; and sodium can form radioactive sodium-24, an emitter of hard gamma radiation with a half-life of about 15 hours. Soil phosphorus will in part convert to the longer-lived radioisotope—phosphorus-32 with its half-life of 14 days. Also possible is the formation of radiocalcium (Ca^{45}) with a half-life of 163 days, radio-iron (Fe^{59}) with a half-life of 47 days and other radioactive isotopes.

When the explosion takes place, the material of the bomb shell is subjected to a terrific neutron irradiation. It, too, will serve as a source of radioactive elements entering the fireball. Noteworthy in this case is the possibility of the formation of radioactive iron-59 and radioactive cobalt isotopes: Co^{56} (half-life, 80 days), Co^{58} (half-life, 72 days) and Co^{60} (half-life, about 5 years); manganese-54 (half-life, 310 days) and certain others. The quantity and quality of the radioactivities produced by neutron radiation during the explosion (the induced type) differ essentially depending upon the nature of the burst.

In a high-altitude air burst, all the neutrons will be absorbed by the air, the main reaction being:



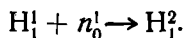
which means that the nitrogen of the air will produce radioactive carbon-14 (C^{14}) with its very long half-life of 5,600 years. The explosion of a megaton fission-fusion-fission bomb produces 10 kg. of neutrons. If one-fifth of them react with the nitrogen of the air, the result will be 28 kg. of radioactive carbon.

The burst of an all-fusion bomb will give rise to ten times as many neutrons, and, hence, will produce ten times as much radiocarbon—280 kg.

At present, the earth, including the atmosphere, the biosphere and the waters of the oceans, has some 80,000 kg. of C^{14} produced from nitrogen under the action of cosmic radiation. Of this amount the atmosphere contains, about 1,200 kg. (1.5 per cent). Just a few explosions of all-fusion or fission-fusion-fission bombs of the megaton class is sufficient to double the amount of radiocarbon in the atmosphere.

Reacting with the oxygen of the air, radiocarbon produces radioactive carbon dioxide. It will be recalled that carbon dioxide is quickly absorbed by green plants in photosynthesis. Then, via vegetables, the radioactive carbon enters animal and human organisms. We should not lose sight of the fact that carbon is a constituent of all the vitally important substances of our body. The presence of radiocarbon will not only increase the total irradiation, but can lead to a specific type of breakdown of these substances. Particularly hazardous is the incorporation of radiocarbon into the organic substances of the chromosomes of the reproductive cells, for this can considerably increase the frequency of deleterious effects in the offspring. A separate chapter will be devoted to this problem.

In an underwater burst, a large portion of the neutrons will be absorbed by the hydrogen of the water with the conversion of the former to heavy hydrogen—deuterium:



In addition, some of the neutrons will be captured by ions of sodium and magnesium with the formation of the relatively short-lived sodium-24 and magnesium-27 isotopes.

Induced radioactivity is greatest in the case of a ground burst, and falls off rapidly in time in the case of underwater and ground bursts, as may be seen from the tabulation below concerning the induced activity (in curies) produced by a megaton fission-fusion-fission bomb.

Time after explosion	Air burst	Underwater burst	Ground burst
0	6.4×10^4	1.4×10^9	2.8×10^{12}
At end of 1 hour	6.4×10^4	5×10^8	1.2×10^{11}
" " 1 day	6.4×10^4	6×10^4	2.8×10^9
" " 1 week	6.4×10^4	4×10^3	4×10^8

During an explosion, all the radioactive substances that form are rapidly injected into the upper layers of the atmosphere, where, due to cooling, they condense from the gaseous state into liquid droplets and, finally, into the solid state, forming a very fine dust suspended in the air. This is known as aerosol.

In low- and medium-yield bursts, most of the radioactive material is condensed at an altitude of 8 to 15 km., that is, it remains in the troposphere, forming, together with water vapour, a radioactive cloud.

In high-yield bursts, part of the radioactivity is thrown into the stratosphere. But no matter how high the radioactive materials ascend, after cooling and condensation they begin slowly to settle down to the surface of the earth. Calculations and direct observations show that deposition from the troposphere occurs within weeks and months following the explosion. Large quantities of activity produced in ground or underwater bursts are known to fall out even during the first few hours after the explosion.

A ground burst produces an enormous crater and, depending on the force of the explosion, from 10 to 100 million tons of ground dirt is sucked up into the fireball. In November 1952, the ground burst of a 5-megaton bomb at the Eniwetok Proving Ground (U.S.A.) gouged out a crater over 1.5 km. in diameter and 51 metres deep. This means that 50 million tons of earth was drawn up into a fireball close to 5 km. in diameter.

The fireball rapidly ascended to a great height, yet considerable fall-out of radioactivity occurred very soon after

the detonation. Deposition from the stratosphere and the upper levels of the troposphere proceeds slowly and will continue for approximately ten years after the burst. Most of the radioactive materials produced during the explosion have very short lifetimes and, apparently, decay before reaching the earth's surface. This category includes all isotopes with half-lives in minutes, hours, and even several days. However, by far not all the radioisotopes have such a short life-span. Below is a list that includes isotopes with half-lives exceeding half a year.

Krypton-85	10 years
Rubidium-87	6.1×10^{10} years
Strontium-90	28 years
Ruthenium-106	about 10 months
Cesium-137	33 years
Cerium-144	9 months
Illinium-147	2.2 years
Europium-155	1.7 years
Cobalt-60	5 years
Manganese-54	about 1 year

Of this list, only krypton is harmless. Being an inert gas, it disperses in the upper layers of the atmosphere and does not contribute to the radioactivity on the ground. But all the others settle to the surface and increase the natural radioactive background, thus affecting living organisms, which include human beings.

The particularly dangerous radioisotopes are those with lifetimes over 10 years—strontium-90, cesium-137 and rubidium-87.

In an effort to justify the testing of nuclear weapons, the advocates of atomic warfare assure the public that there is no harm whatsoever in radioactive fall-out. Their argument is that the surface of the globe is very large. The radioactive fall-out is dispersed world-wide and the average amount of radioactivity at any one point is, they say, negligibly small, so small, in fact that it is absolutely out of the question to speak of a hazard.

Such are the claims of some scientists in the United States, who are carrying out the orders of their bosses: "justify the nuclear arms race." But the facts upset these statements. Let us see what direct observations and rigorously established scientific facts concerning the quantity of radioactive fall-out that is deposited in different parts of the world have to say.

V. THE DEPOSITION OF RADIOACTIVE FALL-OUT AFTER NUCLEAR TEST EXPLOSIONS

The type of radioactive fall-out differs with the power and place of the explosion. The rate of deposition varies with the quantity of radioactivity produced in a given burst; and this, as we have seen, depends on whether the shot was fired in the air or on the ground. Again, the rate of deposition depends on the size of the particles: large particles of diameter hundreds of microns settle down at the rate of roughly 3 km. per hour and fall out within 10 hours after the explosion. Particles 10 microns in diameter fall out in about two weeks, while smaller particles remain suspended in the air, their deposition depending mainly on water vapour condensing on them to form rain-drops. Atmospheric precipitation (rain, snow) is an important agent in bringing to earth the radioactive products of nuclear tests. Finally, the height to which the radioactive substances are carried in the burst is a significant factor.

In the detonation of kiloton atomic weapons the fireball reaches only the upper layers of the troposphere. All radioactive substances are retained in the troposphere (about 16 km.)—the weather region with air currents, winds, clouds and rains. This is why a large portion of these radioactivities begins to fall out rather soon after the burst (hours and days) in the area of the shot, forming what is known as close-in or local fall-out. The smaller particles, in the form of a radioactive cloud, are very soon caught up by the prevailing air current which blows main-

ly from west to east. These winds move at high speeds carrying the radioactive clouds several times around the globe, and all the while the radioactivity settles down to earth with the atmospheric precipitation. This is often called tropospheric fall-out. And contamination is not confined to the immediate vicinity of the explosion but covers huge areas mostly lying in the same latitude as the burst.

Now in megaton bursts large quantities of radioactive material are injected beyond the troposphere into the stratosphere. Precipitation from the stratosphere takes a long time. It can last for years, during which time diffusion and mixing of air masses spreads the radioactive material throughout the stratosphere. Fall-out can then occur at any place on the earth. This stratospheric fall-out can take ten years after the shot was fired to settle down.

Of course, from the viewpoint of the injurious effects, inflicted on human beings, the most dangerous is the local

Table 2

Radioactive Fall-Out from Nuclear Explosions

	Fall-out		
	Local	Tropospheric	Stratospheric
Portion of earth's surface over which fall-out occurs	Within hundreds of kilometres of the explosion	Belt round the earth in the latitude of explosion site	All over the earth
Duration of fall-out	A few hours to a few days	A few weeks or months	About 10 years
Relative distribution of fall-out:			
(a) Air burst	Small (~10 per cent)	30 per cent	60 per cent
(b) Ground burst (kilotons explosion)	66 per cent	33 per cent	Not over 1 per cent
(c) Ground burst (megatons explosion)	25 per cent	25 per cent	50 per cent

fall-out, which is deposited in large quantities and is capable of building up considerable activity. Second comes the tropospheric fall-out, and, finally, the smallest contribution to the radioactive background of the earth is made by the stratospheric fall-out. But it is world-wide. A rough description of the different kinds of fall-out for various types of burst is given in Table 2.

A megaton bomb yields 1,000 kg. (one ton) of fission products; twenty-five per cent of this amount is deposited in the form of local fall-out (250 kg.). Depending on the particle size and the weather conditions, local fall-out can settle down over various-size areas. Calculations show that during twenty-four hours, a person in a fall-out area of 25,000 sq. km. would receive a lethal dose of radiation (about 500 roentgens).^{*} If the fall-out is distributed over an area of 250,000 sq. km. the dose for one day comes out to roughly 50 roentgens, for two days—67 roentgens (it does not double due to the rapid decay of short-lived isotopes). It will be shown later on that these dosages represent a serious hazard to the offspring of irradiated persons. It is interesting to note that a country, such as Great Britain (without the dominions and colonies) occupies a territory of 245,000 sq. km.

A comparison shows that while the shock wave of a megaton bomb damages an area that is only hundreds of times greater than that struck by the shock wave of a kiloton atomic weapon, the radiobiological danger after a megaton explosion covers an area one thousand times greater, which is to say that megaton bombs are in the main a radiological weapon.

The classical case of local fall-out was observed in the fission-fusion-fission explosion at Bikini Atoll in the Pacific Ocean during the "Castle" test. The shot was fired just a little above the coral reef of the island, with the result that

^{*} The roentgen is a unit of radiation dosage. A quantitative definition of the roentgen (and of other units, such as the rem and rad) is given below on page 54.

the entire coral atoll was sucked up to form the radioactive cloud. Extensive fall-out of radioactivity began within only 4 to 5 hours after the explosion.

However, during this brief period of time the radioactive cloud had moved hundreds of kilometres downwind from the point of explosion and activity continued to fall out beyond the "danger area" that is beyond the immediate range of the bomb. Three hours after the shot, a Japanese fishing boat, the *Fortunate Dragon*, which was hit by the fall-out [6] was 130 km. to the northwest of ground zero, while another Japanese vessel, which likewise observed deposition of fall-out, was sailing 120 km. to the northeast of the explosion. This, approximately, determines the fall-out area.

The fall-out settled down in the form of a very fine powder during 4 to 5 hours. The density was such that it was impossible to discern surrounding objects through the falling dust. The dust covered the decks completely, it found its way into every crack and crevice, got under the clothing of the fishermen, was inhaled into their lungs, got into their eyes, and ears, and settled into their hair, the creases of their clothing, and onto the foodstuffs.

A study of this dust carried out by Japanese scientists [6] showed it to be extremely active during deposition which, of course, is understandable, since only a few hours had passed since the detonation, and many of the radioisotopes, even those with short half-lives, were extremely radioactive. According to the information of the Japanese scientists, the activity of the fall-out was then equal to one curie per gramme, which is that of pure radium!

The radioactivity fell out in quantities of 40 to 50 gm. per square metre. Twenty-two fishermen that were in the fall-out zone were exposed to a strong external radiation. If the fall-out activity is taken to be one curie per gramme and if we allow for the fact that the fishermen were in the zone of continuous fall-out, they were subjected to a total-body exposure in the course of five hours, which makes the

total dosage of radiation approximately 200 to 300 roentgens—a very high dose. The radiation must have been considerable during the fall-out because nausea and vomiting began within 3 to 4 hours, skin burns appeared, and radiation sickness developed within 10 to 12 days. The symptoms and severity of the radiation illness were aggravated by the fact that a considerable quantity of radioactive substances was ingested and continued to enter the organism with contaminated food during almost a week of sailing back to the Japanese shores. As we know, all the fishermen had grave cases of radiation sickness and, despite measures taken, the radio-operator of the vessel, Aikishi Kuboyama, died seven months after the explosion from severe damage to the liver by radioactive fall-out [6, 9]. After nine months, spermatogenesis ceased in all the fishermen—they became sterile. Spermatogenesis was restored only a year later.

The fall-out that afflicted the Japanese fishermen consisted mainly of the fused elements of the coral atoll where the shot was fired, and contained radiostrontium (Sr^{89} and Sr^{90}), uranium, plutonium, calcium-45, a lot of cerium-144, chlorine-36 and other radioactive elements.

It should be pointed out that the situation of the Japanese fishermen would have been considerably worse if the main portion of the fall-out had not been washed from the decks of the ship, which continued to sail almost a week. Recalling that the fall-out activity was one curie per gramme and the density 50 grammes per square metre, one week should have made the dose of external radiation no less than 3,000 roentgens, which is many times in excess of an absolutely lethal dose. At sea it is an easy matter to wash away most of the radioactivity, but on land a similar burst will cover thousands of square kilometres with fall-out that is extremely difficult to get rid of. And the radiation hazard will be very great.

The March 1, 1954 burst, as was reported much later [10], was also responsible for a dosage of 15 to 175 roent-

gens to twenty-eight American servicemen participating in the test and 239 Marshallese islanders that were quite some distance from the explosion. Sixty-four Marshallese received the biggest dose—175 roentgens. Press reports

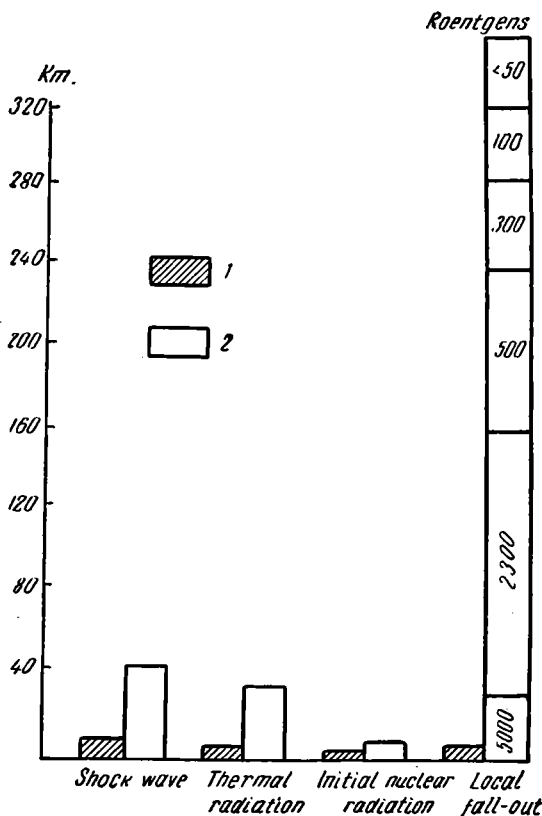


Fig. 10. A comparison of the results of a fission bomb and a fission-fusion-fission bomb (radiation doses produced by local fall-out are given for 36-hour exposure).

1-fission bomb (20 kilotons); 2-fission-fusion-fission bomb (15 megatons).

from the United States stated that a year after the incident all those afflicted had recovered and were back at work. However, in 1958 it became known from papers read at the radiological congress in Barlington, that the Marshallese people, which in 1954 had been exposed to radioactive fall-out, were exhibiting very marked long-range effects of the radiation: enhanced predisposition to infectious diseases, skin trouble, premature aging and others.

All those affected were over 300 km. from ground zero. Local radioactive fall-out from the Bikini explosion covered an area of about 18,000 sq. km., which is far greater than

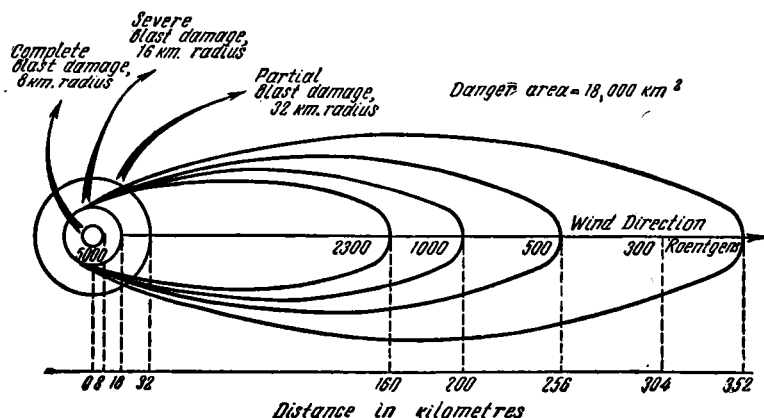


Fig. 11. Fall-out pattern for the explosion of a fission-fusion-fission bomb on Bikini Island March 1, 1954 (radiation doses refer to exposure of 36 hours).

the areas of the biggest cities of the world with their suburbs. (To take an illustration, Greater New York, that is, New York City and suburbs, occupies an area of 6,500 sq. km.)

This scale of local fall-out is characteristic of a high-yield fission-fusion-fission bomb (15 megatons TNT equivalent). This is clearly shown in Fig. 10, which compares

the effect produced by a nominal atomic bomb (20 kilotons) and a high-yield fission-fusion-fission bomb (15 megatons).

The size of the area affected by local fall-out and its shape around the explosion site vary greatly depending on the weather conditions, in particular, on the wind velocity. The contaminated area downwind is usually in the shape of an elongated ellipse.

The fall-out pattern in the March 1, 1954 explosion at Bikini Island is schematically shown in Fig. 11 [3].

According to official American data published February 15, 1955 [11], at a distance of 253 km. from the explosion site radioactive debris began to fall out 8 hours after the detonation and continued for several hours. At 640 km. from ground zero, the total dose of radioactive fall-out was still 50 roentgens.

The case of the Japanese fishermen shows how dangerous local fall-out is at considerable distances from the explosion site. And we see that a ground explosion can give rise to intense fall-out over a large territory extending hundreds of kilometres from the point of explosion. This radioactive fall-out brings with it grave ailments to the people in the area.

Let us now examine in more detail the nature of the tropospheric fall-out.

Investigations carried out between 1954 and 1957 by Soviet, American, and Japanese workers give, in the main, coincident results, and clarify this problem completely. To illustrate, let us take a test series (12 shots fired between February 18 and May 15, 1955) in the state of Nevada, U.S.A., near the town of Las Vegas.

Observations have shown that the radioactive cloud ascends to the upper layers of the atmosphere (the zone of constant air currents) and begins a rather rapid movement from west to east. The radioactive materials in the cloud "rain down" to the earth's surface, the fall-out rate depending mainly on the weather conditions. Observations

of radioactive rainfall enables one to determine the speed of such a cloud.

One of the shots of this test series was fired March 1, 1955. By March 8 to 10, the deposition of fall-out was recorded in England and in Southwest Africa, by March 11 in Greece and Western Turkey, March 13-14 at a number of locations in the European part of the Soviet Union, March 16-19 in the eastern regions of the Soviet Union.

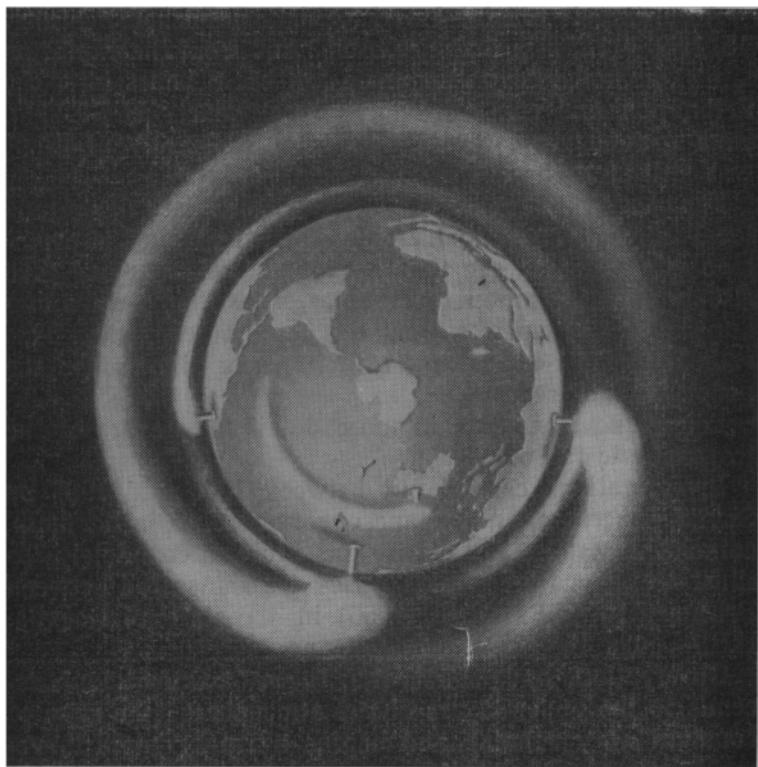


Fig. 12. Types of radioactive fall-out from weapons tests (local, tropospheric and stratospheric) [12].

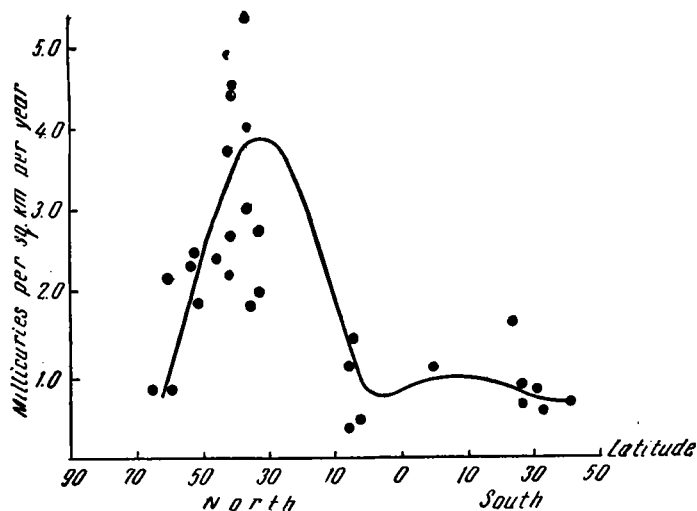


Fig. 13. The distribution of strontium-90 fall-out during one year at different latitudes (data refer to 1956-1957) [15].

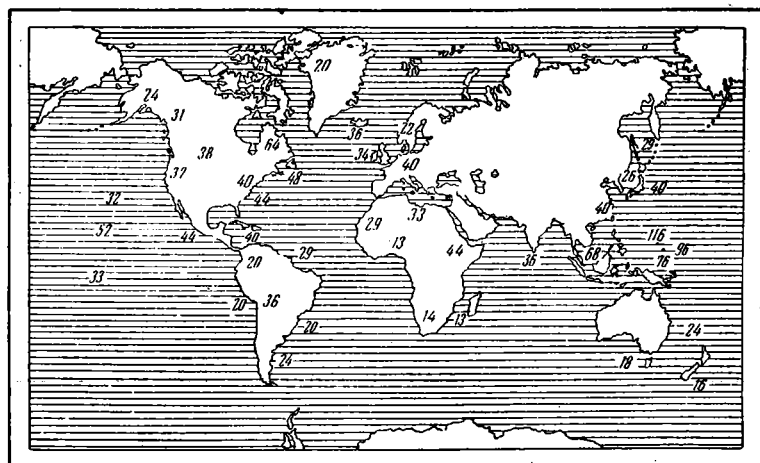


Fig. 14. Cumulative deposition of mixed fission products in millicuries per square kilometre at the stations shown. These data are for fall-out up to January 1, 1956 [13].

It will be seen that in two to three weeks the radioactive cloud moved half way round the globe staying roughly within the latitude of the explosion. In some cases, fall-out from certain explosions was recorded twice; apparently, the radioactive cloud circled the globe and was crossing the same areas a second time. An example is the March 22, 1955 Nevada explosion. In the U.S.S.R., radioactivity was registered the first time on March 29, and a second time in the middle of April. This means that within one month the radioactive cloud which circled the globe was not yet uniformly distributed in the atmosphere. It continued to deposit activity chiefly over those areas over which it passed. True, by this time, the front of radioactive fall-out had expanded considerably, and there was a corresponding reduction in the amount of fall-out per square kilometre. But still the contamination was confined to a specific zone and not uniformly distributed over the earth's surface.

This is pictorially shown in Fig. 12 [12]—the world-wide movement of fall-out—and Fig. 13, which gives the amount of strontium-90 contamination during one year at different latitudes.

Summarizing, we find that since the tests were mainly in the Northern Hemisphere, contamination with radioactive fall-out was highest here, especially in the middle latitudes.

At present, observations of fall-out are made throughout the world. The precision attained by radiometric apparatus permits not only determining the total quantity of activity deposited on a given plot, but even stating the radioactive elements. Fig. 14 is a map of the world-wide deposition of radioactive fission products (in millicuries per square kilometre) as of January 1, 1956 [13].

Some localities in the U.S.A. were particularly contaminated. This was apparently due to the test shots in Nevada.

By September 1955, radioactive contamination had reached the following values [13]:

**Mixed fission
products, mc/km²**

Albuquerque, N. Mex.	160
Billings, Mont.	64
Chicago, Ill.	56
Grand Junction, Colo.	296
Memphis, Tenn.	80
Philadelphia, Pa.	44
St. Louis, Mo.	80
Salt Lake City, Utah	272
San Francisco, Calif.	18
Scottsbluff, Neb.	80
Washington, D. C.	36

The conclusions from these data are: 1) that already in 1956 the entire globe had enhanced radioactivity due to the deposition of the fission products of atomic bombs; 2) that this deposition is highly irregular. There are areas in which the activity is from three to five times higher than the mean values. Apparently, the constancy of air currents, the terrain, and type of precipitation produce more fall-out in some locations and less in others. This is why one should never speak in terms of mean values when assessing the radiological hazard, for areas with an elevated level of radioactivity are very large and very often are densely populated.

But particularly perturbing is the regular increase, from year to year, in the level of radioactivity. It has been pointed out earlier that the finely divided radioactive materials produced in an explosion take a very long time to settle to the earth's surface. Calculations show that deposition of fall-out can continue approximately ten years after the explosion. And direct measurements accord with the theory.

Fig. 15 gives the measurements of strontium-90 content in the soil carried out by Japanese scientists [14] over the course of several years. From these data we see a regular increase in the quantity of radioactive strontium on the earth's surface.

Measurements in the U.S.S.R., the U.S.A. and other countries have yielded close results. For example, the following [15] are strontium-90 measurements in New York.

Period measured	Quantity of Sr^{90} (mc./km ²)
April 1954 - March 1955	0.89
January 1955 - December 1955	2.16
October 1955 - September 1956	4.57
July 1956 - June 1957	7.48

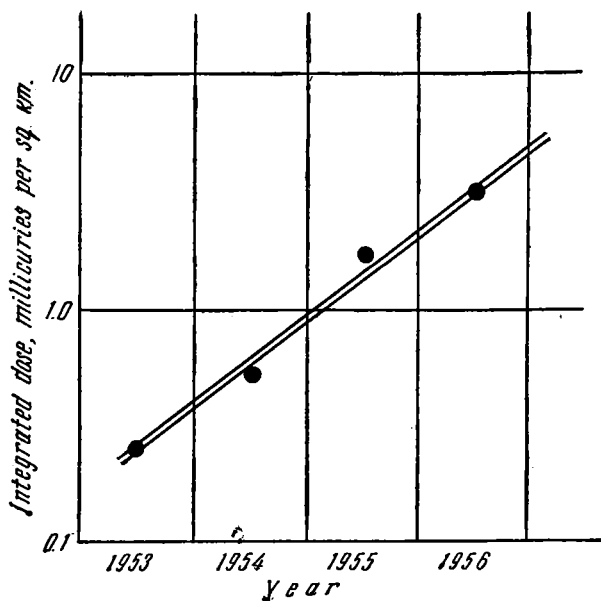


Fig. 15. Strontium-90 increase in the soil of Japan during 1953-1956 [14].

As of the end of 1957, the level of strontium-90 contamination was: in Japan, 8 mc./km.², Great Britain, 8 mc./km.², the U.S.A., from 4 to 21 mc./km.², the U.S.S.R., from 3 to 10 mc./km.²; cesium-137 contamination in Japan and Sweden was about 6 mc./km.²

It is possible to calculate what the level of contamination of the earth's surface with radioactive substances will be in the immediate future. The findings of Japanese scientists with respect to strontium-90 are given in Fig. 16 [14].

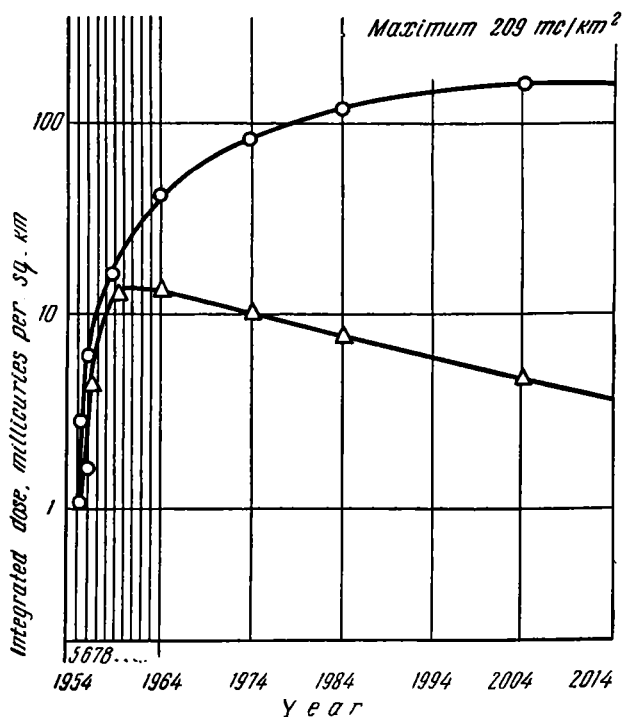


Fig. 16. The future for strontium-90 accumulation in the soil. Curve with open circles refer to strontium 90 content in the soil if tests continue at the 1954-1956 rate. The curve with triangles shows strontium-90 in the soil if testing had been stopped in 1956 [14].

From Fig. 16 it will be seen that even if test explosions had been stopped completely in 1956, the level of contamination would continue to increase up to about 1962. Only

then would there begin a slow decrease due to the decay of the fall-out. But the testing is still going on (1959). The second curve in Fig. 16 is based on the assumption that the tests will continue at the same rate as in 1954-1956. The sharp rise in the contamination is all too apparent. Under these conditions, in thirty years the radioactivity from fall-out will have increased something like one hundred-fold over 1955. And one should not forget that these curves are based on the number of explosions made during 1954-56. But since then, Great Britain has begun testing, and, if proper agreement is not reached, it is probable that other countries will begin within the next 10 years. Moreover, there is no assurance whatsoever that coming tests will not exceed the 1954-56 level, in which case the curve of increasing radioactivity will become even steeper.

Calculations carried out by different investigators in 1957 yielded the following possible strontium-90 contamination levels for various countries:

	Sr. ⁹⁰ contamination, mc./km ² :
Great Britain	350
U.S.A.	370
Sweden	180
Japan	360
Argentina	160

The United Nations Scientific Committee on the Effects of Atomic Radiation, working on the assumption that as yet an equilibrium deposition of strontium has not been reached, has come to the conclusion that if the testing is continued at the 1956-58 rate, the level of radioactive contamination can reach 272 mc/km.² [15].

One can easily imagine what the curve of increasing radioactivity will look like if an atomic war should break out any place in the world. Even at present, when single bombs are exploded and comparatively rarely, there is a rapid rise in the level of contamination of the earth with radioactivity. If dozens of nuclear bombs are dropped at

some place on the earth, all countries, no matter how far away, will be subjected to such a mounting deposition of fall-out that within a few years the level of radioactivity would begin to threaten normal life on earth. And this is to say nothing of the colossal physical damage and number of people killed in the region of the explosions.

What is the hazard to mankind of this increase in radioactivity of the earth's surface? Are the radioactivities that have already fallen out dangerous? What will the danger be in 10 to 50 years? How will it affect our children? These are the questions that deeply concern all of us. I shall try to answer them.

VI. THE ACTION OF RADIOACTIVE RADIATIONS ON LIVING ORGANISMS

Soon after the discovery of the phenomenon of radioactivity at the end of last century, facts began to accumulate concerning the strong and injurious effect of these radiations on living cells, tissues and organisms.

The first investigators of these radiations did not yet know of the danger, and working with radioactive substances without proper protection, became seriously ill and died before their time. We are now well aware of the effects that radioactive radiations produce, and we know that they depend primarily on the dose of radiation received by the organism. When radioactive radiations pass through any substance (air, water, human tissue) they convert the neutral molecules of these bodies into active ions. It is this property of all such radiations that gave them the name "ionizing." The more intense the radiation, the greater the ionization of the material. This is why the quantity of ionizing radiation is usually measured by the strength of its ionizing action. The unit of the X-radiation and the closely related gamma radiation of radioactive substances is that amount which is capable of producing in one cubic centimetre of air a quantity of ions sufficient to

produce a charge of one electrostatic unit. This is called a roentgen.

A dose of one roentgen is equivalent to the absorption, by one gramme of tissue, of an energy roughly equal to 93 ergs. The roentgen unit is applicable only to X-rays and gamma rays, which have similar properties. Other ionizing radiations, such as neutrons or alpha particles produce a different density of ionization. To make comparative measurements of all types of radiation possible, another, purely physical, unit was introduced—the “rad.” One rad is the quantity of ionizing radiation which is equivalent to the absorption of 100 ergs of energy in one gramme of matter. One rad causes the formation, in one cubic micron of irradiated tissue, of about two ionized molecules and approximately the same number of molecules in the excited state. As regards X- and gamma radiation, one roentgen and one rad differ but slightly (93 ergs for the roentgen and 100 ergs for the rad). In assessing the biological action of radiation, frequent use is made of the “rem” (“roentgen equivalent man”), a unit applicable to any type of ionizing radiation. A rem is that quantity of any radiation which produces in living tissue the same biological effect as one roentgen of X-rays.

Table 3 will give the reader some idea of the quantity of ionizing radiation in one roentgen or one rem (for X- or gamma rays) as applied to cases common in everyday life.

What amount of ionizing radiation is injurious to a living organism, to living tissue or a living cell? It is not so easy to answer this question, because organisms, tissues and even cells differ as to their sensitivity to ionizing radiation. This is very clearly seen in Table 4, which gives the dosages (in rems) that are fatal to the irradiated organisms in 50 per cent of the cases.

From the table it is seen that a whole-body dose of 400 rems to human beings is lethal. The eggs of some insects are killed even by a dose of 40 rems. But if the criterion

Table

Some Common Dosages of Radiation

Radiation source	Irradiation time	Dosage in rms
Natural radiation (cosmic rays, radiation from dispersed radioactive elements)	In a lifetime of 60 years	From 10 to 20
Luminous instrument dials in airplane cabin	One year	1.3
Luminous wrist-watch dial	One year	0.04
A chest X-ray	—	From 0.3 to 10
An X-ray of the gastro-intestinal tract	—	From 10 to 50

Table 4

The Relative Radiosensitivity of Different Organisms
in a Single Whole-Body Exposure

Organism	Energy (in rms) sufficient to kill 50 per cent of the irradiated organisms
The eggs of Calliphora	40
The larvae of Drosophila	130
Guinea pig	200
Dog	300
Man	400-500
Monkey	500
Mouse	500
Rat	600
Rabbit	800
Triton	3,000
Molluscs	20,000
Yeast	30,000
Bacteria	100,000-300,000

is not the death of the organism, but various disturbances of the normal vital functions, it will be seen that far smaller doses of radiation are capable of bringing about considerable aberrations. A few are given in Table 5.

It should also be borne in mind that the individual radio-sensitivity also varies within certain limits. There are

Table 5

Radiosensitivity of Various Vital Functions

Dose of irradiation, rems	Organism	Type of alteration produced
200	Man	Radiation sickness. Physically incapacitated.
100-200	Man	Radiation sickness.
50-100	Man	Alterations in blood composition, isolated radiation injuries.
25-50	Man	Alterations in blood composition.
25-50	Mouse (female)	Alteration of oestrous cycle, reduced fertility.
50	Rat	Reduction of oxidizing phosphorylation in the mitochondria of the spleen.
20	Rat	Temporary cessation of cell division in the epithelium of the cornea of the eye.
12.5	Rootlet cells of Tradescantia	Cell division processes disturbed.
2	Frog	Suppression of mitotic activity of epithelium cells of cornea of the eye.
1	Mouse	The appearance of altered blood cells (thrombocytes).
1	Mouse	Anomalies of spermatogonia.
0.3	Mouse	Anomalies of lymphocytes.
0.056 (for 6 days)	Mouse	Change in the speed of passage of a nerve impulse through the synaptic junction of the reflex arc.
0.05	Fruit fly	Altered duration of life cycle.

always some individuals of a species that are more sensitive, and others that are more resistant.

The radiosensitivity of the human organism is least of all explored. However, through studies of the effects of the atomic bombings of Nagasaki and Hiroshima and an analysis of material obtained from animal experiments, it is possible to gain some insight into the effects of different dosages on humans in the case of whole-body exposure (Table 6).

Table 6 is based on single exposures. On the whole it may be said that although certain organs are very sensi-

Table 6

**The Probable Effect of Single Whole-Body Exposure of
Humans to Gamma Rays**

Irradiation dose, rems	Fatal in 24 hrs.	Fatal in 6 weeks	Percentage incapacitated in the first 24 hrs.	Probable time of incapacity of survivors
0-25	0	0	Negligible	2 to 3 days
25-75	0	0	Isolated cases	2 to 3 days
75-100	0	Less than 0.1 per cent	About 50 per cent	1 to 2 weeks
100-150	0	Less than 0.5 per cent	At least 50 per cent	About 3 weeks
150-200	0	About 5 per cent	At least 75 per cent	Radiation sickness for at least 3 weeks
200-400	Highly improbable	About 30 per cent	Probably 100 per cent	Same
400-600	Isolated cases	About 50 per cent	100 per cent	Same
800 and over	Probably several cases	Probably 100 per cent	100 per cent	—

tive to radiation, injurious doses in the case of single exposures must be comparatively large.

Though such big single doses as 50 rems do initiate changes in the blood (a decrease in the number of lymphocytes), the latter are rather quickly overcome and in one to two weeks the organism appears to recover.

Chronic (continued) exposures produce a different effect. Experiments have shown that in chronic exposure to ionizing radiation a so-called cumulative effect is operative. If a dog receives a dose of 25 rems, it is almost impossible to detect any changes in its organism. But if the dog receives this dose every day for 8 to 10 days, the integrated dosage will amount to 200-250 rems, producing typical radiation sickness with all the characteristic signs that would be observed if the dose had been given all at once. If the daily dose is reduced, more time will pass before the effect becomes evident. For instance, at 5 rems per day, the ailment can be induced not in 40 days (when

the overall dose reaches 200 rems) but in 60 to 70 days with an integrated dose of 300 to 350 rems. Thus, two processes are operative: one, accumulation of the dosages, the other, processes of regeneration that retard the onset of the illness and make necessary a larger total dosage than in the case of a single exposure. Now if the dose is reduced to 3 and 1 rem per day, acute radiation sickness will not be induced at all; however, the cumulative action will still be operative, though its effects will be apparent only after considerably longer intervals of time. Such small doses of chronic radiation can continue for months and even years without exhibiting any effects. But afterwards there appear what are known as distant effects of chronic irradiation. They find expression primarily in the appearance of malignant tumours. This is the worst effect of chronic irradiation. Observations of animals have shown that under the influence of small chronic radiation they age sooner, have a shorter life-span, became less resistant to infectious diseases and more frequently succumb to infections. This is the peculiar effect of small dosages of radiation.

Now, what if the daily dosage is reduced still further? What are the doses that do not produce any injurious effects? A correct answer to this question is extremely important at the present time when more and more people are coming into contact with ionizing radiations.

The efforts of many scientists have been aimed at determining what are known as tolerance doses of radiation. International conferences have repeatedly discussed the results of observations with the purpose of establishing a dosage that would have no deleterious effects even when a person is exposed to it every day. In 1925, the harmless dose was 0.2 rem per day or 60 rems per year. But already by 1935, data had accumulated showing that this dosage is not entirely harmless, and the National Bureau of Standards of the United States proposed cutting it in half, making the permissible dose 0.1 rem per day or 30 rems per year.

In 1950 the Sixth Congress of Radiologists discussed new observations of the appearance of hereditary diseases in chronic irradiation. The congress recognized the dose of 0.1 rem per day to be harmful, and reduced it by a factor of two. At the present time, the permissible dose for occupational irradiation in many countries, including the Soviet Union, is taken at 0.05 rem per day, or 0.3 rem per week, or 15 rems per year.

However, though these doses are not harmful to the person exposed, they can lead to certain alterations in the reproductive cells. If a large number of persons with such alterations in the reproductive cells marry, it is possible, given certain combinations, that in succeeding generations there will appear anomalies, monstrosities, and nonviable offspring. This is why the congress pointed out that while taking the value 0.05 rem as permissible for limited groups of persons in contact with an occupational hazard, it proposes for the population at large a dose reduced once more by a factor of 10. To summarize, then, doses that do not exceed 0.005 rem per day, or 1.5 rems per year may be regarded as comparatively harmless for the entire population. But no one can be sure that this is really the lower limit. We have seen that during the past 30 years this figure has been progressively reduced in line with our expanding knowledge of the effects of radioactive radiations. But information obtained directly from observations on the human organism is very scarce. Not very much is known even about the effect on anthropoid apes. The principal conclusions have been drawn from observations on animals, and it is possible that further research will make necessary a revision of this figure.

In 1957, proposals were made to reduce again these standards by a factor of three. If they are sufficiently justified the permissible dose will come out to 0.016 rem per day or 5 rems per year for persons connected with occupational hazards, and 0.0016 rem per day, or 0.5 rem per year for the population as a whole.

The doses of radiation that we have been dealing with are very small. They are more conveniently measured in thousandths of a rem—millirems (mrem). This would put the permissible dose of radiation for the population at 500 mrems a year.

We now come to the questions: What are the actual doses of radiation that the inhabitants of this planet are exposed to? What is the added radiation from radioactive debris that is falling out? Can one really speak of a hazard? Let us examine them in some detail.

VII. WHAT IS NATURAL RADIOACTIVITY, HOW MUCH IS THERE AND HOW IS IT INCREASING FROM NUCLEAR EXPLOSIONS?

All living organisms, it turns out, are constantly exposed to small doses of radiation in the region of thousandths of a rem. Studies of the earth's surface show that the natural radioactive elements—uranium, thorium and radium—are found in minute traces in nearly all terrestrial rocks. For example, radium is found to the amount of 10^{-12} per cent and uranium, 10^{-6} to 10^{-5} per cent. It is these vanishingly small traces that create the constant background of radioactivity in our environment. What is more, radium, uranium and thorium enter the organism with food and, to some extent, are deposited in it (mainly in the bone tissue). This adds to the radiation dose from these elements.

Another naturally radioactive element is potassium, which, it will be recalled, is frequently encountered in nature. Many of the minerals are salts of potassium. Potassium is a constituent of living organisms. The human body is 0.26 per cent potassium. Plants are richer still—1.5 per cent. Natural potassium consists of three isotopes, graphically presented in Table 7.

It will be seen from Table 7 that the bulk of natural

Table 7

The Composition of Natural Potassium

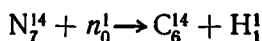
Isotope and mass number	Percentage in natural mixture	Radioactivity
Potassium-39	93.08	Non-radioactive
Potassium-40	0.0119	Radioactive, beta and gamma emitter. Half-life, 10^9 years
Potassium-41	6.91	Non-radioactive

potassium is made up of isotopes 39 and 41, which are not radioactive. However, natural potassium invariably has a tiny amount of the long-lived radioactive isotope potassium-40, which, like uranium, radium and thorium, creates the natural radioactive background of our environment.

Due to all these elements, our body is exposed to an average radiation dose of 80 mrem/year. In wooden houses it is less—60 to 75 mrem/year; in brick houses more—130 mrem/year, while in concrete buildings it may even be as much as 200 mrem/year. These differences are due to the different quantities of natural radioactive elements in the materials of construction.

Human beings are also exposed to radiation from the radioactive substances within the organism. Potassium is found dispersed in all organs and tissues, whereas radium, uranium and thorium are concentrated mainly in the bone system. Together, these internal emitters, which operate mainly against the skeleton, produce roughly 44 mrem/year according to the data of the United States Atomic Energy Commission.

In the upper layers of the atmosphere, cosmic rays are constantly producing the following reaction with the formation of radioactive carbon, C^{14} .



This radiocarbon combines with the oxygen of the air producing radioactive carbon dioxide. Together with or-

dinary carbon dioxide, the radioactive type is absorbed by plants in the process of photosynthesis, and with vegetation is ingested by animals and humans. The admixture of radiocarbon is very small, but modern instruments are capable of detecting it. The human organism is exposed to another 1.5 mrem/year due to radioactive carbon in the body.

In addition to these sources, living organisms are constantly exposed to cosmic radiation. It has been reliably established that outer space is pierced with ionizing radiations of tremendous energies. These cosmic radiations strike the terrestrial atmosphere giving rise to new radiations that are mostly absorbed in the upper layers of the atmosphere, though a part reach the surface of the earth. Thus, cosmic radiation is another component of the constant natural background of radioactive radiation on the earth. At sea level it is 30 mrem/year. But at an altitude of 1,500 metres it is already twice as much—60 mrem/year. At high-mountain altitudes (6,000 metres above sea level), cosmic radiation yields a dose of 450 mrem/year.

Table 8

Dosages Due to Natural Radioactivity

Source of radiation	Skeletal dose rate, mrem/year		
	Minimum at sea level		Maximum at 1,500 metres above sea level
	After Dudley and Evans [16]	After Libby [17]	
Potassium-40 (internal)	8	19	19
Carbon-14 (internal)		1.5	1.5
Radium, thorium (internal)	36	73.7	73.7
Cosmic rays (external)	30	35	60
Local gamma rays (external)	60	80	200
<i>Total</i>	134	209.2	354.2

Table 8 gives the overall dosage that our bodies are exposed to from the natural background radiation.

Probably country dwellers living in wood houses ex-

perience minimum doses of natural activity, while urbanites in reinforced concrete buildings are exposed to maximum doses. It is interesting to note that the increasing frequency of medical X-rays given not only to sick persons whose symptoms require it, but also to people in normal health during annual prophylactic screening, add more and more to the overall radioactivity that the population is exposed to. This has become particularly alarming due to the increasingly frequent use of X-rays for commercial purposes, such as shoe-fitting. Some fashionable dress-making establishments in the United States and Britain even go so far as to make X-rays of the spinal column. The U.S. Atomic Energy Commission estimated that, on the average, the population of the country receives annually from X-rays a dosage close to that of natural radiation—approximately 100 mrem/year.

What is the dosage of external radiation added by fall-out from nuclear bombs? The principal role is played by those isotopes that have sufficiently hard gamma radiation. They include primarily cesium-137 (0.66-Mev gamma rays).

In some places on the earth, the radiation from these elements reached 60 to 70 mrem/year in 1955. This is one-half the natural radioactive background. In most places, these values were between 0.1 and 0.06 of the natural background.

The following is a table of the gamma dose (in mrad/year) due to radioactive fall-out between Oct. 1951 and Sept. 1955 according to the data of Eisenbud and Harley [13].

Albuquerque, N. Mex.	110
Billings, Mont.	24
Grand Junction, Colo.	20
New Orleans, La.	27
New York, N. Y.	17
Rochester, N. Y.	13
Salt Lake City, Utah	160
Scottsbluff, Neb.	26
Washington, D. C.	11

By 1957 the quantity of long-lived radioactive fall-out had increased by 2 to 4 times. There is every reason to believe that within the next 10 years it will increase at least tenfold.

External gamma radiation will increase with less intensity since it is due mainly to the short-lived isotopes. However, the accumulation of cesium-137 in our environment will regularly increase the radiation that our bodies are exposed to. We shall see later on that any increase in exposure to radioactivity will lead to a higher incidence of leukemia and cancer, and to greater genetic damage (hereditary diseases). However, this danger is far less than that due to the ingestion of radioactive fall-out by humans. In this case, not only gamma- but beta-emitters, too, will become a hazard. Strontium-90 is particularly dangerous. It is a beta-emitter with a half-life of 28 years. Just what kind of a hazard is this?

VIII. HOW RADIOACTIVE FALL-OUT GETS INTO THE BODY

The long-lived radioactive isotopes—strontium-90, cesium-137 and cerium-144—that settle to the earth's surface are incorporated into the general cycle of matter and quickly penetrate into living organisms. A particular concern is strontium-90 due to its ability to concentrate selectively in different parts of the organism.

Strontium-90 is deposited on the surface of the earth chiefly in radioactive rain-out, and is absorbed by the upper layers of the soil, whence it easily finds its way into plants via the root system. Livestock eats the grass containing strontium-90 and assimilates it. Chemically, strontium is very similar to calcium and they are usually found together in the living organism. Calcium, it will be recalled, is contained in large quantities in milk. Radiostrontium follows the calcium into milk, which is then ingested by the human organism. Most of the calcium in food is used

to build and exchange bone tissue. Together with calcium, radioactive strontium is deposited in bone tissues in the skeleton. Bone tissue stores away the ingested strontium, which is eliminated from the bone very slowly. Only in certain cases is this process speeded up, for example, in nursing mothers. During lactation the female organism releases large quantities of calcium together with milk. Part of this calcium is borrowed from the bone tissue. Radioactive strontium that has deposited in the skeleton of the mother likewise gets into the milk with the calcium. It then enters the organism of the child where it is almost fully assimilated, being used to build growing bone tissue. From the mother's organism, radiostrontium can enter the blood of the foetus and its skeleton through the placenta.

When strontium gets into bodies of water, it is very actively absorbed by algae and plankton. Concentrations of strontium-90 in plankton can exceed those in the water environment by 10,000 times. From here it gets into the organisms of molluscs, crabs and fish. Measurements show that the concentration of strontium-90 in fish bones is 700 times greater, and in fish muscles 500 times greater than in the surrounding water. In Japan, after the Pacific explosions, large parties of tunny, mackerel and other fishes were found to be rather radioactive. The liver and skeleton were particularly active. When the fish is prepared for food, a considerable part of the strontium is left in the edible part of the fish, while in fish preserves all of the strontium of the bone tissue is retained. These are the main pathways into the human organism for strontium-90.

Since strontium always accompanies calcium, some scientists have devoted special attention to the strontium-calcium ratio in the soil, in food and in the human organism. It was suggested to measure not the absolute quantity of strontium, but the amount per gramme of calcium. A special unit was introduced—the sunshine, or strontium unit—equal to 1 micromicrocurie ($\mu\mu\text{C} = 0.000,000,001$

curie) per gramme of calcium. A calculation of the radiation energy of this quantity of strontium-90 shows that one strontium unit produces a radiation dose to the bone tissue equal to 2.7 mrems per year. A determination of the ratio of strontium-90 deposited in the soil to the calcium in the soil exhibited a soil average of 50 strontium units in 1956. On the basis of rather limited experiments, the American scientist Libby concluded that in the natural migration of strontium and calcium along the food chain "soil-plant-animal-milk-man," strontium is discriminated against relative to calcium. Calcium is more easily assimilated by the organism so that the strontium-90-to-calcium ratio continuously diminishes. It was suggested that nature has a specific protective mechanism, called a factor of protection, which reduces the relative quantity of strontium in its transfer through the food chains. On the basis of rather limited experiments and analyses, it was taken that in the transition from soil to plant the factor of protection is two, which means that the strontium-90-to-calcium ratio is halved. In the plant-to-animal-organism transition, this factor is 7, while in the passage from milk to the human organism it varies between 2 and 8, making an average of 5.

On these assumptions, the overall factor of protection in the transition of strontium-90 from the soil to the human body was found to be $2 \times 7 \times 5 = 70$. Therefore, if in 1956 the soil contained an average of 50 strontium units, the human organism should have roughly 70 times less, that is, less than one strontium unit. This is a very small quantity, which in one year produces a radiation dose to bone tissue less than 3 mrems.

From the foregoing, Libby draws the conclusion that there can be no talk of a hazard from strontium fall-out, that atom bomb testing can continue, the atomic arms race can be pushed forward, and that it is even permissible to carry out limited atomic wars [18]. This line of reasoning is followed by some other American scientists (for ex-

ample, Teller and Latter) in their attempts to justify the testing of nuclear weapons and the atomic arms race. As we shall see later on, there are not so many such scientists, and they are not supported even by their American colleagues who are more independent of those circles that profit by the arms race.

Selective determinations of strontium-90 in the bones of adults carried out in 1956 showed that the quantity varies between 0.5 and 0.8 strontium unit. These findings were likewise utilized as added proof of the correctness of the view that experimental atomic bomb tests are harmless.

Let us examine these contentions in the light of all the facts available at the present time.

It is known that plant leaves actively absorb dissolved substances that deposit on them. It has been proved by tracer techniques (tagged atoms) that when fields of cultivated plants are sprayed with a solution of phosphate (containing labelled phosphorus), the plants intensely absorb the phosphate that has settled onto the leaves, and it finds its way to the developing fruit faster than does the phosphate that enters the plant via the soil and the root system. The possibility of leaf feeding by means of so-called leaf fertilizers has not only been established in experimental conditions, but is widely in use at present in practical agriculture. Therefore, radioactive strontium that is rained down to the surface of the earth will in large quantities be assimilated directly by the plant leaves. This has been confirmed by observations of Soviet scientists, N. V. Gulyakin and Y. V. Yudintseva [19]. The radiostrontium bypasses the soil and is assimilated by plants in the absence of calcium, which fact should considerably increase its relative percentage measured in strontium units. This circumstance partially eliminates the effect of the first factor of protection. But even if we consider strontium-90 entering the plant through the roots, it is hardly possible to speak seriously about a factor of protection of 2 for all soils and all regions of the globe.

Investigations carried out chiefly by Soviet scientists [20-22] clearly show that the intensity with which strontium enters plants from the soil varies markedly depending on the composition and physical properties of the soil, the plant species, the amount of non-radioactive strontium in the soil and the ratio of assimilable to non-assimilable calcium in the given soil. It was found that for one and the same quantity of strontium in sandy loam and sandy clay soils, the former enters the plant five times more intensely from sandy clay than from sandy loam soil. In another case, oats absorbed four times more strontium-90 than peas in the same soil. This shows that the factor of protection 2 is very approximate and, apparently, is detected only in certain specific experimental conditions and is valid only for some soils and plants. Indeed, a direct determination of the strontium-90 content in plants in certain parts of the U.S.A. in 1955 came out to 19 to 80 strontium units for hay—this is almost the same as that found in the soil. The conclusion, therefore, is that the first factor of protection is not universal, and in some regions is absent entirely.

The second and third factors of protection that discriminate against strontium in the transfer from plant to cow and from milk to the human organism are also limited. The American scientists reasoned only from the diet of the American population. They were apparently not in the least interested in hundreds of millions of people in other countries, with other customs, ways of living and habits of diet. An examination of the diets of all countries and peoples shows that in many countries plant foods make up the bulk of the food supply. In this respect, rice is of great interest, being one of the staple food products of the East (Japan, China, Korea, etc.). Rice is rich in strontium. Nearly 43 per cent of all the strontium ingested by the inhabitants of these countries comes from rice. The strontium to calcium ratio in rice is 40 times greater than in milk, which explains why more strontium is assimilated.

The Pacific Ocean Island dwellers take in still larger quantities of strontium (about 63 per cent) with food prepared from marine fish, which has a strontium to calcium ratio 10 times above that in milk. Thus, in addition to the gradual migration of strontium-90 through a series of intermediaries, there are short-circuited food chains that promote the build-up of strontium-90 in the human organism. This is illustrated in Fig. 17.

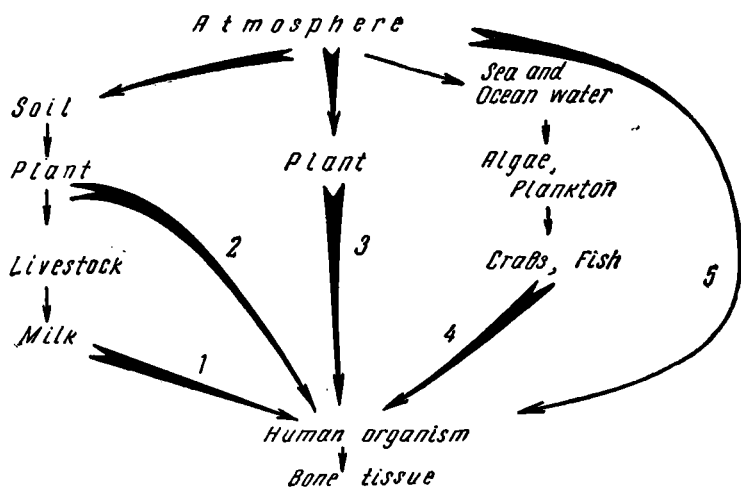


Fig. 17. Transfer of strontium-90 along food chains.

Particularly dangerous is the appearance of radioactive strontium in the young, growing organism of children. Radiobiologists have long been aware of the fact that the young organism is far more vulnerable to the action of radiation. According to present-day legislation in the U.S.A. and other countries, persons below the age of 18 may not be employed in the atomic industry for the reason that young, growing organisms are most easily affected by radioactive radiations. At the International Conference on Radioisotopes in Scientific Research held in September 1957, the American scientist Taylor [23], speaking on be-

half of the International Radiological Commission, proposed a maximum permissible dose of 5 ($N-18$) rems for a life span of N years, where N is the age of the person. From this it follows that persons below the age of 18 cannot receive ionizing radiation in addition to the natural background without endangering their health. Now it is

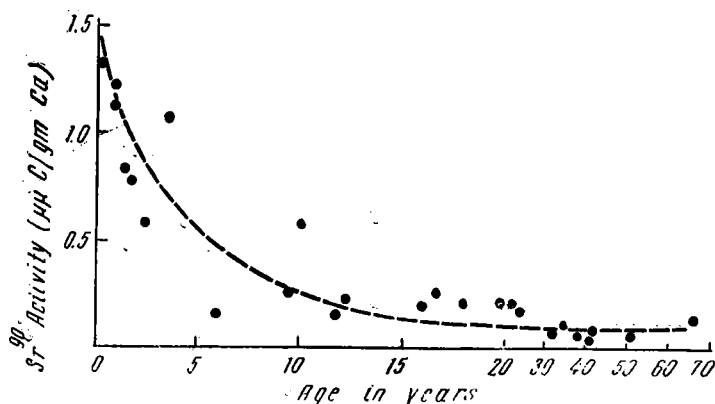


Fig. 18. Strontium-90 activity in human bones in 1955-1956 [24].

precisely the organism of the child that is quickest to absorb radiostrontium deposited as a result of test explosions. Special studies have shown that when strontium-90 gets into the organism of the mother, it passes with the blood stream through the placenta, and is deposited together with calcium in the developing skeleton of the foetus. To build a skeleton, the developing foetus takes up large quantities of calcium from the mother organism. And the calcium is accompanied by radiostrontium earlier deposited in the skeleton of the mother.

During breast-milk feeding, the organism of the mother again requires a good deal of calcium. During this period, all the calcium in the food is assimilated by the mother. If the food of a nursing mother contains radioactive strontium, during this period it is completely absorbed by the

organism along with calcium. Once again we see that the factor of protection in the transition of strontium from food to the human organism is totally dependent on the physiological state of the organism and that in the case of a nursing mother it falls to unity. Radioactive strontium, together with calcium, passes mainly into the milk of the nursing mother and from there into the organism of the child where it is almost completely utilized by the rapidly growing bone tissue. In 1955-56, direct determinations of the quantity of radioactive strontium in the bones of persons of different age groups yielded a sufficiently clear picture (Fig. 18) despite the small amount of material [24].

It may be seen from the figure that already in 1955-56, that is, only a few years after regular nuclear weapons testing began, the quantity of radioactive strontium in the bones of children one to three years of age proved to be many times greater than in the bones of adults. These data refer to years when the level of radioactive strontium in the environment was still relatively low. Analyses of the bones of children carried out in 1957 yielded, for some localities, from 2 to 4 strontium units (Japanese data).

Such is the rapid rate at which the quantity of deleterious radiostrontium is increasing in the bones of people.

To date, sufficient experimental evidence has piled up enabling us to make scientifically substantiated forecasts of the extent of the radioactive hazard due to nuclear-weapon explosions. True, in many respects our knowledge is imperfect; in most cases, we are only able to give the approximate range and not the exact figures.

On a number of questions views differ. The ultimate result of investigations often depends on which hypothesis is used as a basis.

When it is a matter of foreseeing all hazards and saving human life scientists must select, from among all pos-

sibilities (based on the latest scientific data), the *worst* one, and it is their duty to warn people about the danger.

We have already spoken of the possible contamination of the earth's surface with radioactive strontium. In order to calculate the possible amount of strontium in the bone skeleton, one needs to know the factors of discrimination, that is, the factors which show the reduction of radiostrontium per gramme of calcium when passing from one link of the food chain to another (discrimination factors are the reciprocals of the factors of protection mentioned above).

The difficulties to determining these factors can be judged from Table 9, which is a collection of data on the discrimination factor in the food-bone transition obtained by different workers.

It may be seen from Table 9 that in the case of man this factor can fluctuate between 0.54 and 0.17.

Table 9

The Discrimination Factor in the Food-to-Bone Transition

Organism	Food	Value of the discrimination factor	Source
Man	Milk	0.54 (0.50-0.62)	[25]
Man	Milk	0.48	[26]
Man	Mixed	0.24	[27]
Man	Non-milk	0.44	[25]
Man	Non-milk	0.35	[28]
Man	Mixed	0.25	[29]
Man	Mixed	0.17	[26]
Rat	Milk	0.57	[30]
Mouse	Non-milk	0.35	[31]
Rabbit	Mixed	0.20	[31]

However, the main difficulties in calculating are due to the different possibilities there are of strontium entering the organism.

It will be seen from the diagram in Fig. 17 that the first pathway includes the largest number of discrimination factors: K_1 (soil $\rightarrow$ plant), K_2 (plant $\rightarrow$ cow), K_3 (cow $\rightarrow$

milk) and K_4 (milk $\rightarrow$ human bone). Soviet scientists [20] have shown that there are particularly sharp fluctuations in K_1 depending on the amount of calcium in the soil, the nature of the soil, and the plant species cultivated on this soil.

The second pathway has only two factors of discrimination: K_1 (soil $\rightarrow$ plant) and K_2 (plant $\rightarrow$ bone), and the third, only one, K_3 (plant $\rightarrow$ bone).

The peculiarity of the fourth pathway is that plankton is capable of concentrating radioactive contamination from the water environment, and this leads to inverse values of the discrimination factor. And, finally, the fifth pathway, which has been explored least of all. This is direct absorption via respiration and the pores of the body (the latter case is particularly dangerous to the inhabitants of hot climates).

The concentration of strontium-90 in human bones (in strontium units) can, in the general case, be calculated from the formula

$$C = K_1 \cdot K_2 \cdot K_3 \cdot \frac{1}{A} D \cdot 10^9,$$

where K_1 , K_2 and K_3 are the respective discrimination factors, A is the quantity of assimilated calcium in the soil, and D is the contamination of the soil with strontium-90 in millicuries per square kilometre.

As we have already seen, if testing is continued, D may reach 270 mc/km², A (according to the data of Hiyama [32]) may be taken as equal to 95×10^6 gm/km² (with a spread between 30×10^6 and 230×10^6 gm/km²).

For a population that obtains most of its calcium from milk, it is well to take K_1 (soil $\rightarrow$ plant) = 0.5; K_2 (plant $\rightarrow$ milk) = 0.16; K_3 (milk $\rightarrow$ bone) = 0.5.

$$C = 0.5 \cdot 0.16 \cdot 0.5 \cdot \frac{1}{95 \cdot 10^6} \cdot D \cdot 10^9 = 0.42 D,$$

if C is expressed in strontium units, and D in mc/km².

Of course, if the soil is richer in calcium, the total factor will diminish accordingly. According to data for Great Britain, it can be equal to 0.15.

For a population with a predominating vegetation diet (rice, wheat, rye, vegetables), K_1 (soil $\rightarrow$ plant) = 0.5; K_2 (plant $\rightarrow$ bone) = 0.35.

Hence,

$$C = 0.5 \cdot 0.35 \cdot \frac{1}{95 \cdot 10^3} D \cdot 10^9 = 1.8 D.$$

The usual diet is a mixed one. The relationships of plant and milk food in different countries may be judged from the data in Table 10.

Table 10

Calcium in Diets in Different Countries [15]

Country	Daily intake of calcium, mgm.		
	Cereals, vegetables, etc.	Milk and milk products	Fish and marine products
Canada	109	780	—
Great Britain	370	585	12
Japan	264	20	106

It should be pointed out that the Japanese diet, in which plant foods are ten times as important as milk products, is typical of many countries of the East, Central Asia and India, and that in a country like Britain, plant foods lag only a little behind milk products as regards intake of calcium into the organism. If all this is kept in mind, it will be clear that if one bases his calculations (as Libby does) on a factor of 0.1, or even (as Teller and Latter [33] do) on 0.05, the result will be a deliberate reduction in the extent of the hazard that confronts us, it will mean calculating for practically non-existent diets. With our aim of determining the maximum extent of the possible hazard, we will be close to the truth

if we assume that the vegetation intake is the same as that of milk (in specific weight) and if we take the average value of the maximum probable factors, that is:

$$\frac{0.42+1.8}{2} = 1.11.$$

We may thus expect that if testing continues the future concentration of strontium-90 in human bones will reach a value of $C=1.11 \times 270$, or 300 strontium units.

Calculations conducted by other methods give figures that are in close agreement.

Analyses, carried out in 1957, of the bones of children up to five years of age showed them to contain from 1.1 to 4.1 strontium units. These data refer to children born in 1952-1956. Prior to 1955, the quantity of strontium in the environment was less than 0.89 millicurie per square kilometre even in the United States, which is the most contaminated country. In 1955 it was 2.1 mc/km², in 1956-1957 the average contamination had risen to 5 mc/km². The parents of these children, whose bone analyses have just been given, did not have any strontium-90 in their bodies. Consequently, even if it is taken that two strontium units is characteristic of the environmental contamination, which during this period was an average of 1.95 mc/km² this value should increase in the future in proportion to the increasing contamination of the environment, that is, it should equal $(2 \times 270) : 1.95 = 275$ strontium units, or, in other words, be of the same order of magnitude as was arrived at above.

In one year, one strontium unit produces 2.7 mrad. This means that if tests continue, the radiation to the bones due to radiostrontium can increase to $300 \times 2.7 = 810$ mrad. This exceeds by many times the radiation dose to bones due to natural background radiation (135 mrem per year), and, as we shall soon see, is a big hazard to the health and lives of human beings.

When considering the danger to human life from strontium-90 getting into the organism, an added point of interest is the uneven distribution of strontium in the bone tissue. Uneven distribution takes on a peculiar significance when we regard such biological processes as originate under prolonged irritation of the tissue. Apparently, this is an important factor in the origination of malignant tumours.

At the present time it is a well-known fact that long-continued irritation of one and the same section of living tissue can bring about a regeneration of this tissue with the formation of a malignant tumour. So-called cancerogenic carbohydrates are capable of the greatest irritating action. Their systematic application to one and the same section of the skin invariably produces tumours. However, data from the literature show that other substances can also produce a cancerogenic effect if the action is sufficiently protracted. Physical agents, for instance, ultraviolet rays and, especially, radioactive ionizing radiations, produce this same effect. Again, the necessary condition for the development of tumours is continuous action against a single section of tissue. It is a simple matter to show that precisely such conditions are created when radioactive isotopes get into the organism and are localized in some organ or in some parts of an organ. If a bone is sectioned and, in the dark, is put onto a photographic film, those places in the bone in which the radioactive element has concentrated will radiate and, upon development of the film, will show up dark. It is as if the radioelement "signs" that it is present. This is why such radiograms are often called radioautographs.

Fig. 19 is a radioautograph of the bone of an animal that had ingested strontium-90. The distribution of strontium and radium in bone tissue is very similar. We find that their distribution is by far not so uniform as is ordinarily taken in averaged calculations. The radioactive element concentrates almost entirely in the quick-growing

parts of the bone—epiphyses—in which some parts are very much richer in the isotope than others. The localization of radiostrontium in the feebly mineralized structures of the bone tissue creates peculiar centres of radiation, which exposes the near-lying tissue to far greater daily doses than are found in averaged calculations.

Those who claim that the testing of nuclear weapons is harmless often point out that the natural external background radiation of man experiences greater fluctuations than the mean increase in irradiation due to radioactive fall-out [18]. In this comparison, the localized action of radioactive substances that get into the body is ignored completely.

To illustrate, let us suppose that the radiation (in rems) from an external source and from a substance that has entered the bone tissue is the same and very small. Does this mean that the biological effect will be the same? By no means. External radiation produces ionization uniformly distributed in the

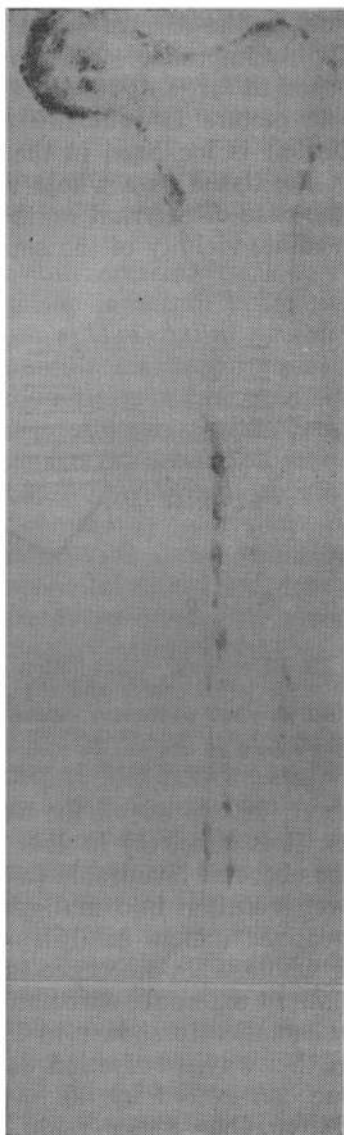


Fig. 19. Radioautograph of section of bone containing strontium-90.

tissue. In the case of small external radiation sources, it is highly improbable that some one group of cells will be exposed to large doses of radiation.

The picture is radically different when the source of radiation is localized in the tissue. Though, on the average, the tissue as a whole will receive the same dose as in the case of external radiation, the group of cells in the immediate vicinity of the source will receive a continuous

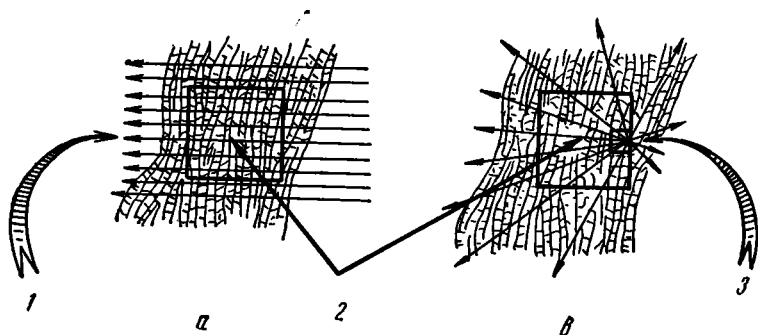


Fig. 20. Differences in irradiation of tissue by equal doses from (a) an external source and (b) an incorporated local source.

1-no cell group will receive more radiation than the other cells of the tissue; 2-cubic centimetres of tissue receive equal number of ionizations in both cases; the dosages are equal; 3-a group of cells near an incorporated emitter receives a far greater dosage. These cells will be exposed to constant irradiation.

dose at the expense of the weaker irradiation of the other cells. It is precisely in this group of cells that the conditions become favourable (a continuously acting stimulus) for regeneration into malignant tissue; and, as we know, a localized tumour easily spreads, affecting the organism as a whole. This difference in the action of radiation from a diffused external source and from incorporated emitters is schematically shown in Fig. 20.

In this way, irradiation dosages of certain parts of the tissue can exceed by 40 to 60 times the mean levels of radiation, thus considerably increasing the hazard due to ingested strontium.

The assimilation of radiostrontium by the human organism depends not only on the strontium to calcium ratio in food, but also on the ratio of strontium-90 in the food products to the natural non-radioactive strontium isotopes, Sr^{88} , Sr^{86} , Sr^{84} , Sr^{87} .

Japanese scientists [34] have proposed expressing the quantity of radioactive strontium not in units of sunshine (1 micromicrocurie of Sr^{90} per gramme of Ca), but in units of moonlight—the ratio of radiostrontium to the total amount of strontium in the skeleton, the latter being equal to approximately 7 grammes. The unit of moonlight will then be one micromicrocurie of Sr^{90} to every 7 milligrammes of Sr. These units (moonlight and sunshine) coincide for bone tissue, but differ markedly with respect to, say, the soil or food. This difference is due to big fluctuations in the strontium to calcium ratios.

It is quite obvious that in localities with small amounts of strontium in the soil and in plants, radioactive fall-out strontium will have a considerably greater relative value (in moonlight units) than in soils that are rich in strontium. If one also takes into account that under normal conditions the human organism is constantly assimilating a certain amount of strontium with food (experiments have shown that a diet totally lacking in strontium does not permit normal development of the organism), it will be clear that radioactive strontium will be taken up in greater quantities in those districts where there is more of it in moonlight units, though in terms of sunshine units (relative to calcium) these districts will not differ from the others.

The foregoing facts show how uneven is the uptake of radioactive strontium by the human organism. Averaged calculations are not very acceptable when determining the real danger to persons living in different parts of the world. If a stop is not put to the testing of nuclear weapons, within the next few decades there will be large

areas on the globe representing a real hazard to the life and health of the inhabitants, due both to an increased radioactive background of the environment and to internal radiation from radioactive substances.

This problem is discussed in the next chapter.

IX. THE DANGER TO MANKIND FROM THE ACCUMULATION OF STRONTIUM-90 AND AN INCREASE IN THE NATURAL RADIATION

We have seen that the continuing tests of nuclear weapons lead to a systematic increase in the natural radiation level, to the penetration of radioactive fall-out into the human body and to the deposition of strontium-90 in the bones. Extensive areas, measured in the thousands of square kilometres, particularly in regions adjacent to the explosion sites, are already observing substantial increases in radioactivity, increases that permit speaking of a hazard in these areas. In the Northern Hemisphere, an area covering about 30 per cent of the total surface of the earth and including the most populated regions has the highest radiostrontium contamination. If the test explosions are not stopped, it will steadily increase. Over the entire surface of the earth, the natural radioactivity is increasing and will continue to do so the more intensely, the higher the yields of nuclear detonations. Below it will be shown that there is every ground for considering that in 30 to 50 years it will have increased to such a point that it will bring grave distress to our children, if nuclear explosions are not stopped.

It goes without saying that if a nuclear war should break out any place in the world it would very quickly develop into a radiological hazard to the entire population of this planet.

In this chapter we shall not discuss the effects on the human organism of large dosages of radiation that can

occur within 100 to 200 km. of the site of the explosion. This has already been dealt with. Our purpose now is to consider the effects of long-continued small doses of internal and external radiation.

All available experimental material indicates that prolonged regular irradiation in small doses produces effects only after a long time reckoned in years and decades. The effect of radiostrontium on living organisms began to be studied only during the past four to five years, and much in this field is still obscure. Great difficulties arise in extrapolating the results obtained on small animals and insects to the human organism. It has been remarked that the radiosensitivity of different types of animals varies greatly. This complicates extending to humans the experimental findings obtained on animals, particularly small rodents, with which most of the research has been carried out. More reliable results have been obtained in experiments with dogs. An interesting paper by Ward [35] appeared in 1957, in which the author shows that monkeys are far more sensitive to strontium radiation than other experimental animals.

It is obvious that at present we can make only a very tentative assessment of the hazard to man due to an increase in the background radiation. An important point to note is that test animals have lifetimes of only 2 to 3 years and so the effects of small radiation doses can be observed only during this relatively short period of time. A person who from childhood has had extra strontium-90 in the bones will be exposed to small radiation dosages for 10 to 20 years and more. The effects may be deleterious although such small doses are ineffective in animal experiments.

However, despite the fact that it is exceedingly difficult to give a direct answer to the questions that have been posed, we have at our disposal data that permit foreseeing the possible danger. These data have been obtained from

extensive experimentation with animals, from observations of humans irradiated in the Nagasaki and Hiroshima bombings, and of persons who have long been exposed to radioactive preparations in their work (persons employed in the production of luminous substances that contain radioactive elements, radiologists, roentgenologists and others).

On the basis of available material, we are obliged to keep in mind the possibility of the following unfavourable effects on man of prolonged exposure to small doses of radiation:

- 1) life shortening, premature ageing;
- 2) increased incidence of bone cancer and leukemia;
- 3) increased number of infectious diseases;
- 4) nervous disorders;
- 5) damage to the immediate offspring and genetic effects of radiation.

Let us examine briefly each one of these possibilities.

Life Shortening. Premature Ageing

Numerous experiments on animals have shown that both single doses and protracted small doses of radiation inevitably lead to earlier ageing of the organism, to graying of the hair, obesity, loss of sexual activity and an earlier death.

For example, research conducted by Lorenz [36] on mice yielded the following results of protracted exposure to small doses of gamma radiation (Table 11).

In regard to certain species of animals it was established that physiological ageing due to radiation is proportional to the dose received. The decisive factor in this case is the integrated dose of radiation absorbed by the organism, and not the time during which this dose is given.

In terms of the human life span, it turns out that 1 rem

Table 11

**Life Shortening Effects of Continued Exposure to
Radiation in Mice [36]**

Daily dose, in roentgens	Average accumu- lated dose, in roentgens	Average life span, in days	Life shortening	
			Days	Percentage of controls
Control	—	703	—	—
8.8	4,300	488	215	30
4.4	2,600	591	112	15
2.2	1,400	630	73	10
1.1	775	684	19	2.7

of ionizing radiation absorbed by the organism shortens the lifetime of the individual by 5 to 15 days.

Statistical studies of the lifetimes of radiologists as compared to other physicians that do not come into contact with ionizing radiation have shown that their average lifetime is 6 years less [37]. It is difficult to estimate the radiation dosage that radiologists receive during their life's work. If it is taken that they receive the maximum permissible dose per day—0.05 rem, or 0.3 rem per week, in one year the dose will be 13.2 rems, and 30 years of work, 396 rems. This gives a life shortening effect per rem of:

$$\frac{6(\text{years}) \times 365 (\text{days per year})}{396 (\text{rems})} = 5.4 \text{ days.}$$

These are values of the same order as those obtained in animal experiments. Other calculations yield values between 1 and 30 days. The most probable figure is apparently 5 to 10 days.

It has already been stated that a megaton bomb explosion produces so much fall-out radioactivity within a radius of 250 km. that the radiation dose is lethal in a 36-hour exposure. At a distance of 300 to 350 km. these doses vary between 300 and 200 roentgens, which, of

course, will not only lead to mass-scale incidence of radiation sickness of various degrees of gravity, but will leave a heavy imprint on the future lives of all those exposed to the radiation, causing premature ageing and earlier death, although it is still difficult to say just how much the life span of people in this area will be reduced.

A radiation dose of 300 to 200 roentgens is an approximate dose for the first 36 hours. During the days that follow, the intensity will fall off rapidly, but radiation from the long-lived fission products will continue for years, though the intensity will be small. Calculations show that the integrated dose for inhabitants of these areas should be in the range of 400-300 rems, which means a life shortening of up to 11 years.

The effects of radiation will be felt even in the more distant areas where the overall dosage is appreciably less (50 to 200 rems), as was the case with large numbers of Marshallese islanders during the Pacific Ocean tests.

The data below [37] give some idea of the relationship between the radiation dose and the probable life shortening.

Radiation received, r	Life shortening (in years)
50	0.7-1.4
100	1.4-2.7
200	2.7-5.5
400	5.5-11.0

We have noted that the average contamination in latitudes of the Northern Hemisphere where the shots are fired (at points distant from the explosions) was from 20 to 60 mc/km² in 1956, though in some localities (Albuquerque, Salt Lake City, Grand Junction, etc.) it reached 160 to 296 mc/km².

Following is a list of the cumulative gamma radiation measured through June 1956 at different stations in the world [38].

Station	Gamma dose, millirads
Albuquerque, N. Mex.	126
Boston, Mass.	56
Detroit, Mich.	34
Grand Junction, Col.	134
New Orleans, La.	36
New York (La Guardia)	31
Philadelphia, Pa.	25
Salt Lake City, Utah	127
San Francisco, Calif.	13
Montreal, Quebec	21
Ottawa, Ontario	18
Hiroshima	22
Nagasaki	27
Tokyo	23
Pacific islands:	
Yap, Caroline Islands	46
Guam, Caroline Islands . . .	149
Truk, Caroline Islands . . .	73
Ponape, Caroline Islands . .	104
Iwo Jima	159

If we compare these figures with the gamma-ray doses obtained by the same authors in 1955 (see p. 63), we will see that the level of radiation has increased due to fall-out. Commenting on these figures, the authors emphasize that the radiation dosage to a person will be greatly reduced due to the protection of buildings. To some extent this is true, particularly for the inhabitants of big cities. But millions of people in the countryside, or those living in primitive conditions will not have this protection, and for them a loss of 1 to 2 years in the life span is realistic in every sense of the word.

We have assumed that the level of radiation of the environment will not rise. This is not true, however. As long as the testing of atomic and hydrogen weapons continues, the radiation of the environment will continue to increase steadily, and, consequently, premature ageing and early death will more and more threaten the population of a considerable part of the Northern Hemisphere.

When considering the life-shortening hazard of ingested radioactive substances produced in nuclear explosions,

one must not lose sight of the possible enhanced effect of the simultaneous ingestion of different radioisotopes. The point is that the radioactive fission products of uranium present a diversified picture of chemical elements, which enter the body and concentrate in different tissues and organs thus aggravating the damage to the whole organism. For example, radioactive strontium concentrates mainly in the bone tissue, radioiodine in the thyroid gland, plutonium and uranium in the liver, etc.

Simultaneous injury to different vitally important systems can markedly enhance the overall effect. This was very well shown in the joint and separate effect on rats of colloidal gold and strontium phosphate [39].

Colloidal radioactive gold is mainly absorbed by the liver and the spleen, while radioactive strontium is absorbed by bone tissue and is effective primarily against the bone marrow. Exposure to 22 microcuries per gramme of colloidal gold alone was not lethal to the rats during 30 days of observations. Exposure to a dose of 1.6 microcuries per gramme of strontium phosphate was lethal to 35 per cent of the animals. But the simultaneous action of much smaller quantities of colloidal gold ($11\mu\text{C/gm.}$) and strontium ($0.8\mu\text{C/gm.}$) was 85 per cent lethal. This obviously enhanced effect is frequently disregarded when assessing the danger of a complex mixture of radioactive substances getting into the organism.

Some scientists in the United States attempt to justify the arms race and allay the fears of common people by comparing the bomb test hazard with other factors of modern life which shorten the life span. For instance, Libby [18], and Teller and Latter [33] have often said that the danger due to test explosions is in no way greater than that caused by smoking or driving automobiles, since accidents annually take the lives of thousands. This comparison carries no weight because the authors purposely "forget" that every person can decide for himself whether to smoke or to drive at high speed or cautiously. A person

can always refrain from smoking or reckless driving. And if he doesn't it is apparently because he believes that the pleasure that he gains compensates for the risks that he takes.

The situation is quite different in the case of test explosions. Here, there is no concern for the interests of the population of the country in which the shots are fired. More, there are victims in other countries as well, and often among people who do not in the least suspect any danger.

Speaking at the International Conference on Radioisotopes in Scientific Research (Paris, 1957), professor L. Taylor of the United States said [23] that the problem of permissible doses of radiation was not a problem for science but one for ethics and morals. But just what are these morals?

Unfortunately, they are the naked morals of a businessman who regards all values from the standpoint of profit. Taylor asks what the advantages are of using a certain quantity of radioactive substances and what the profit will be. And then gives the answer himself: if advantages and profit accrue, then it is worth sacrificing the health of hundreds and thousands of people—let them get sick or die early. These are the ethics of certain circles in the United States which stand for a continuation of the arms race and for more testing of nuclear weapons. They draw enormous dividends from military production and the advantages—to use the language of their ardent supporter, professor Taylor—exceed the risk, all the more so since the advantages are got in the U.S.A., while the risk is for the island dwellers of the Pacific Ocean, where such “moralists” as Taylor prefer to carry out their tests. One would like to know what advantages accrue to the 239 Marshallese islanders who suffered from radioactive fall-out after the Bikini test explosion.

The gratifying thing is that there are not so many scientists like Taylor, and Libby and a few others, who have lost all the principles of humanism that have always

distinguished outstanding men of science. The great majority of scientists throughout the world protest vehemently against the testing of nuclear weapons for they bring distress and grief to people everywhere.

Increased Incidence of Bone Cancer and Leukemia

One of the most dangerous manifestations of long-continued exposure to radiation is the malignant regeneration of tissue, which leads to rapidly growing malignant tumours (cancer, sarcoma) or to an abnormal and unrestricted proliferation of white blood cells (leukemia). Apparently, in both cases it is a case of malignant, that is, uncontrolled growth of tissue, and the difference lies only in the kind of tissue that is affected. It has already been pointed out that malignant regeneration of tissue is generally the result of continued irritation. In this case, the irritant is radiation. Bone tissue creates the most favourable conditions for such protracted irritation, because it is here that one of the longest-lived fission products of uranium—strontium-90—accumulates. Strontium-90, it will be recalled, has a half-life of 28 years. Another long-lived fission product—cesium-137—is dispersed in the fluids and tissues of the human organism and for this reason does not create localized sources of radiation, thereby representing considerably less of a hazard as an agent promoting malignant growth. This is probably also true of external sources of radiation.

In contrast to the latter, strontium-90 is deposited preferentially in the growing parts of the bone skeleton, and, emitting easily absorbed beta radiation, it releases all its decay energy into the adjacent tissue. If an animal is exposed to sufficiently large quantities of strontium-90, it is seen to develop osteosarcomas (which are malignant tumours of the bone) and leukemia due to irradiation of the bone marrow, which, as we know, produces the white blood cells.

It is clear, then, that the increased incidence of leukemia and osteosarcomas is intimately connected with the accumulation of radioactive strontium in the bones. This is why so much attention has been paid during recent years to the fate of radiostrontium released in nuclear

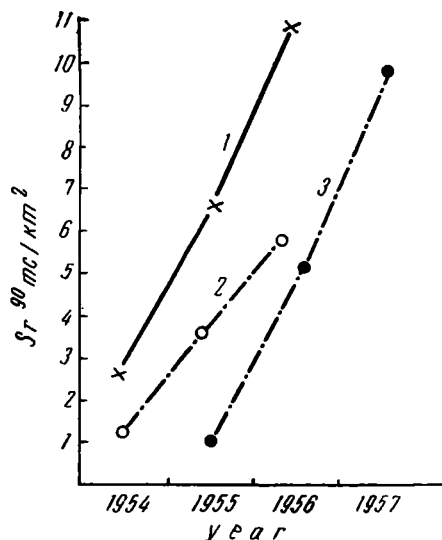


Fig. 21. Curves showing increase in strontium-90 in the soils of the U.S.A. and Britain.

1-New York, U.S.A. [40]; 2-Britain (average data); 3-Pittsburgh, U.S.A. [40].

explosions, to its accumulation in the soil, in plants, animal organisms and, finally, in human bones. Thanks to extensive research, we are now in possession of sufficient experimental material to trace the accumulation dynamics of strontium-90 both in our environment and in bone tissue.

I have already given the characteristic growth curves of strontium in the soil of Japan (see p. 50). Fig. 21

shows the results of measurements in the U.S.A. and Great Britain [40].

These curves show how regular is the increase in the amount of strontium-90 in the environment. The average for 1957 was from 7 to 10 mc/km², but if testing continues it will reach 100 mc/km² in 20 years, 200 mc/km² by the year 2010, and 270 mc/km² by 2040.

In step with this environmental accumulation of strontium-90, there is a regular increase of it in the bones of

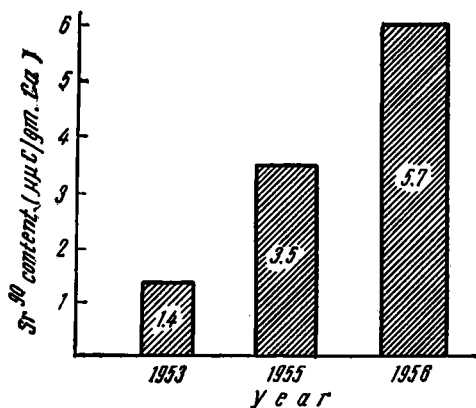


Fig. 22. Increasing amounts of strontium-90 in calf bones [37].

animals and humans. Analyses of calf bones [37] (Fig. 22) vividly show how fast this accumulation takes place.

Very characteristic data have been obtained from analyses of sheep bones [41] carried out in three localities of Wales (Great Britain) (see Fig. 23).

From this diagram it is apparent that the quantity of radioactive strontium in the bones increased nearly 10-fold during three years of observations. The absolute figures differ for different localities (this is apparently dependent primarily on the proportion of calcium in the soil), but the trend of the curves illustrating the rapid accumula-

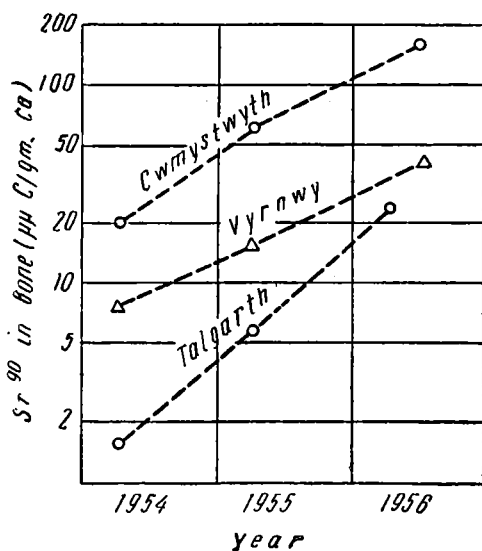


Fig. 23. Strontium-90 in Welsh sheep bones (Britain) [41].

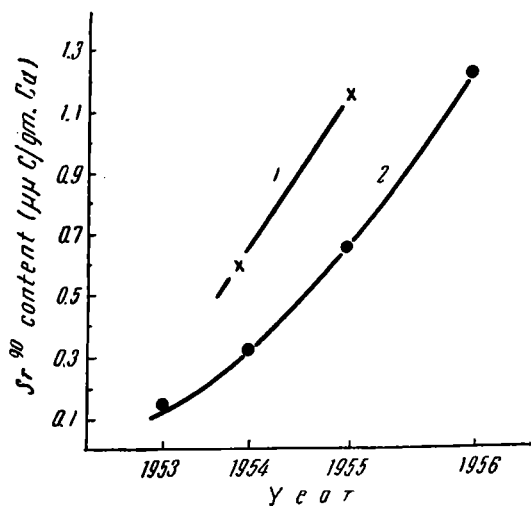


Fig. 24. Strontium-90 in the bones of children.
1-up to one year of age [44]; 2-the bones of stillborn children.

tion of fall-out strontium-90 in sheep bones is the same in all cases. And this is in Britain, which is quite some distance from the explosion sites.

Similar increases in strontium-90 are observed in human bones, as analyses of the bones of children graphically displayed in Fig. 24 [44] indicate. Knowing the dynamics of the incorporation of radioactive strontium into bone tissue and its radiation energy it is possible to compute the doses that human bone tissue is now receiving and will continue to be exposed to if nuclear tests are kept up at the rate of 1954-1956.

Calculations have been given showing the radiation exposure of bone tissue in the next century in the case of established equilibrium. It amounts to approximately 800 mrem per year. The point that must be stressed here is that this is an average figure for the world as a whole. Considerable areas are expected to be exposed to two and three times as much. And again, one should not forget that strontium is not distributed uniformly in bone tissue. There can be from 10 to 40 times more in the vertebrae and epiphyses of the bones than the average figures indicate, and this can expose certain parts of the bones to something like 8 to 30 rem per year.

In 1958, the Japanese scientist Hiyama [43] published similar calculations for the population of Japan with its predominant vegetable food diet. According to his data, by the beginning of the next century, the amount of strontium in human bones will range from 80 to 600 strontium units with a probable average of 240 units. This quantity of strontium will expose bone tissue to an average of 648 mrem per year, while maximum exposure can reach 1,620 millirems in one year!

H. Jones [37], in a discussion of the problem of the incidence of tumours and leukemia due to extra amounts of strontium, likewise comes to the conclusion that within 10 to 20 years bone tissue will be exposed to as much as 200 mrem a year, which coincides with the findings of Hiyama.

What do we know about the effects of radioactive substances on bone tissue? Observations of persons long employed with radium preparations point to a substantial proportion of cases of osteosarcomas and other malignant tumours appearing due to radium getting into the bone [44]. True, there is no extensive statistical material showing the incidence of tumours as a function of the quantity of radium in the bone tissue. The cases described refer to relatively large doses of radium, of the order of 0.15 to 22 microgrammes per skeleton. As a rule, the tumours appeared a long time after the exposure, although, of course, it is hardly possible to determine the actual duration of this period in the majority of cases of occupational poisoning. This compels us to approach cautiously the conclusion drawn by Looney [44] that cumulative doses of the order of 1,000 to 2,000 rems are needed to produce osteosarcomas. In dog experiments carried out by Soviet scientists it has been shown that the introduction of radioactive thorium in doses of 1-0.5 microcuries per kilogramme of live weight caused the death of the animals in periods ranging from 9 months to 2 years and 2 months from the beginning of the experiment [45]. When the dose of radiothorium was reduced to 0.1 microcurie per kilogramme no pronounced symptoms of chronic radiation sickness were observed. Three years after exposure to these dosages, tumours were detected with metastases into internal organs. These tumours originated in the pelvic and humeral bones, in the sternum and in thoracic vertebrae. A histological investigation showed the tumours to be sarcomas of osteogenic origin.

The introduction of 0.1 microcurie of radium into the organism results in irradiation of the skeleton to the extent of 3 r per year [44]. It follows, therefore, that the dog received to the skeleton $10 \times 3 \times 3 = 90$ r. From the foregoing figures it will be seen that many localities in the world that are exposed to excessive strontium fall-out due to continuing weapons tests can easily expect irradiation

tion in the neighbourhood of 3 r per year, which in 30 to 40 years will lead to the development of osteosarcomas on a mass scale.

In discussing the problem of the origination of bone tumours due to strontium irradiation, Mayneord and Mitchell (quoted in [37]) point out that each unit quantity of strontium-90 absorbed by bone confers a certain probability of bone-tumour formation, the tumour development time perhaps decreasing and the tumour incidence increasing with the dose. Other investigators, too [46], arrive at this same conclusion.

It should be emphasized at this point that even the small quantities of strontium that were detected in human bones in 1955-1956 (1.2×10^{-9} curie per skeleton) (the calculations were carried out by A. V. Savich and are quoted in [47]) create dosages of beta radiation to the bone marrow that exceed by tenfold the dose due to the natural radium background in our skeleton (if it is taken into consideration that the alpha rays from radium do not reach beyond the bone tissue).

The United Nations Scientific Committee on the Effects of Atomic Radiation has reviewed the present status of our knowledge on radiation-induced bone cancer and has come to the conclusion [15] that at the present time there is every ground for assuming that any increase in exposure to radiation will increase the incidence of cancer (the so-called non-threshold theory of the origin of cancer). The committee based its calculations on statistical data, according to which there are 10 cases of bone cancer per million individuals. It was assumed that 10 per cent of these cases is due to natural radiation. Then the incidence of cancer due to strontium contamination (N_c) may be computed from the formula

$$N_c = \frac{10 \times 10^{-6} D_{st.} \times 5 \times 10^9}{10 \times D_n}$$

where 10×10^{-6} is the probable incidence of cancer per individual, $D_{st.}$ is the annual dose of radiation to the bone from deposited radioactive strontium, 5×10^9 is the population of the world by the beginning of next century, and D_n is the annual radiation dose to bone tissue from natural sources. Substituting into this formula the probable figures, given above, for D_n (0.1 rad) and for $D_{st.}$ (0.8 rad) we get

$$N_p = \frac{10 \times 10^{-6} \times 0.8 \times 5 \times 10^9}{10 \times 0.1} = 40,000.$$

What this means is that if the testing of nuclear weapons continues at the rate they attained in 1954-1957, then at the beginning of the coming century some 40,000 persons will contract bone cancer every year due to weapons tests!

Studies by Moskalyov [47] have shown that the induction of leukemia in laboratory dogs requires strontium doses one-tenth those that produce osteosarcoma. In other words, the hazard of mass-scale induction of leukemia due to increasing quantities of strontium in the bone is still greater.

One of the most widespread types of leukemia is known as granulocytic (or myelogenous) leukemia, which originates through the malignant regeneration of cells of the bone marrow. This is the type of leukemia that is most probable from prolonged exposure of the bone marrow to the beta rays of strontium-90 that deposits in the bone.

An idea of the proportionality between the incidence of leukemia and the dose of ionizing radiation received by the organism can be gained from the statistics of the incidence of leukemia among the irradiated inhabitants of Hiroshima and Nagasaki, from the frequency of leukemia due to irradiation in medical examinations, and from persons who have contracted the disease occupationally.

A comparison of the irradiation dose and the incidence of leukemia (in percentage) among the inhabitants of

Hiroshima and Nagasaki is given in Fig. 25, which is based on data obtained by Lewis [48].

The probable incidence of leukemia based on these data fluctuates between 0.7×10^{-6} and 4×10^{-6} person per rem per year. Closely agreeing figures (0.4×10^{-6} to 6×10^{-6})

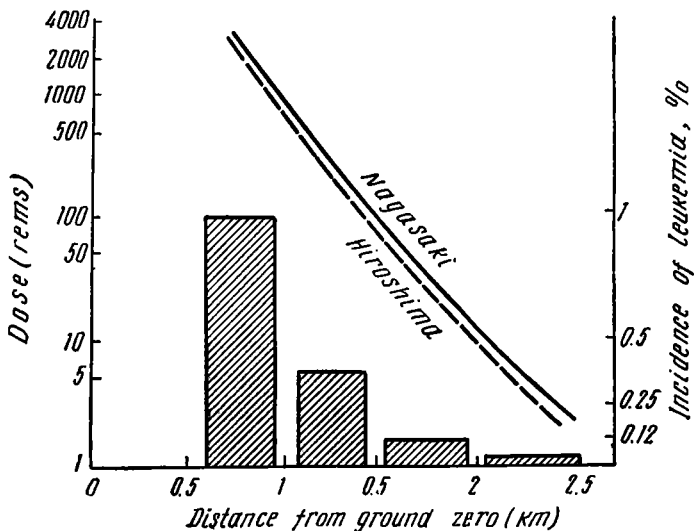


Fig. 25. The relationship between the incidence of leukemia and the radiation dose [48].

have also been obtained from an analysis of induced illness due to medical examinations and through occupational exposure to ionizing radiation (0.7×10^{-6} — 7×10^{-6}).

The closely agreeing figures obtained as to the probability of incidence for greatly differing doses of radiation speaks in favour of a linear dependence, that is, direct proportionality between the dose and the incidence of the disease. This is shown in Fig. 26.

The average incidence for leukemia per rem per year (K) is 2.6×10^{-6} (The United Nations Scientific Committee takes a slightly smaller figure— 1.5×10^{-6}).

Leukemia arises from irradiation of the cells of the bone marrow. The greatest difficulties lie in calculating the bone-marrow dose of radiation from strontium deposited in the bone tissue. One strontium unit in bone is known to yield 2.7 mrem/s per year. The bone marrow immediately

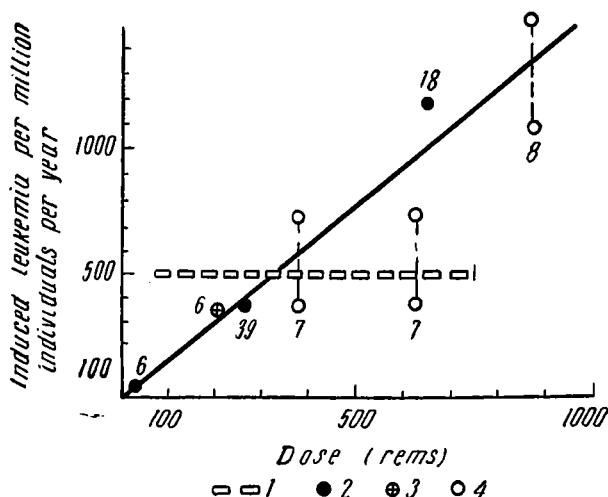


Fig. 26. A linear dependence between the dose and incidence of leukemia (figures under circles are the number of recorded leukemia cases).

1-radiologists; 2-survivors of atomic bombing; 3-X-irradiated children; 4-X-irradiated adults [48].

adjacent to bone tissue or enclosed in microscopic cavities which are surrounded on all sides by bone tissue will receive a dose close to this. In larger cavities, the dose will fall off rapidly amounting to an average of 0.6 mrem per year. Since the process of active blood formation takes place mainly in the microscopic cavities of flat bones, which are exposed to the greatest amount of radiation, we can take, for calculations, the average figure of 1.6 mrem/s per year from one strontium unit.

The total number of possible leukemia cases in the future can be computed from the formula

$$N_{\text{leu}} = K \cdot D_m \cdot M \cdot P \cdot R,$$

where K is the mean incidence equal to 2.6×10^{-6} ; D_m is the bone marrow dose per strontium unit, which we have taken as equal to 1.6 mrem per year; M is the average time in which the radiation dose accumulates and is equal to 35 years for an average life span of 70 years; P is the number of persons in the world in the next century, taken to be 5×10^9 ; R is the strontium contamination of the bone tissue, which, as has already been pointed out, can amount to 300 strontium units.

From this it follows that the possible incidence of leukemia in the future will be equal to

$$N_{\text{leu}} = 2.6 \times 10^{-6} \times 1.6 \times 10^{-3} \times 35 \times 5 \times 10^9 \times 300 = 218,000,$$

that is to say, over two hundred thousand persons annually will contract leukemia if the nuclear testing is not put a stop to.

The foregoing calculations refer to a time when equilibrium will have set in between the radioactive strontium that is falling out and decaying. We need not console ourselves by thinking that this equilibrium will be established only in about the year 2050. Calculations show that much sooner, in about 50 years (2009 A. D.) contamination will amount to 80 and 90 per cent of the equilibrium values, and this yields just about the same figures. Which means that even among the children of our generation there will be hundreds of thousands of deaths due to leukemia induced by radiostrontium. This is the price that future generations will pay for the present tests, if they are not stopped in time!

While doctors throughout the world are bending every effort to reduce the mortality from existing illnesses, continuing tests of nuclear weapons leave in their wake more and more victims that succumb to leukemia. There

can be no justification for the hundreds of thousands who die from leukemia; yet this is but one of the inevitable consequences that await mankind if timely agreement is not achieved on the total and unconditional cessation of nuclear weapons testing. One finds it difficult to foresee how many cases of leukemia there would be if a nuclear war should break out any place in the world. They would undoubtedly be reckoned not in hundreds of thousands but in millions. To determine these figures now is impossible. However, it is obvious that the peoples of all countries, including the aggressor, will pay the dearest price for unleashing an atomic war—the lives of their children.

Increased Number of Infectious Diseases

It is a well-known fact that relatively small doses of radiation produce a sharp decline in the ability of the organism to resist infectious diseases. Several factors are operative in this process. Irradiation greatly reduces the ability of the organs to produce protective antibodies that neutralize the harmful toxins released by pathogenic bacteria. Certain cells of our body (macrophages and microphages) are much less capable of destroying extraneous bacteria that get into the organism during infections. A special protein in the blood—properdine—that plays an important role in natural immunity, is destroyed. Finally, very important is the increased permeability of the walls of the blood capillaries, the mucous lining of the stomach, the skin and other barriers that ordinarily protect the organism from penetration of infections. In radiation sickness, death is frequently the result of reduced resistance of these protective barriers, due to the penetration of infection and the rapid development of the infectious disease.

It is still not clear to what extent these phenomena can occur under small doses of radiation, although isolated observations compel us to regard this possibility, too, with

proper attention. The Soviet scientists P. Kiselyov and P. Buzini [49] have carried out extensive investigations into the chronic effect of small doses of ionizing radiation on immunity. Irradiation was in doses of 1.2 to 4.3 roentgens every 24 hours, and observations lasted up to a year and a year and a half.

The findings were: deranged natural immunity and immunogenesis, and altered sensitivity of the organism to various microbes and toxins.

In 10 months (at a dose of 2.3 roentgens per 24 hours), there was observed a decline in the bactericidity of the blood and in the phagocytic function of the leucocytes.

There was a steep increase in the contagiousness of influenza virus. The greatest weakening of natural immunity and increase in the sensitivity of the organism to the infection was observed in young animals born of individuals that had been exposed to radiation prior to pregnancy and during it [50].

In a study made by D. I. Zakutinsky on dogs, the latter were given daily injections (for 2.5 years) of strontium-90 with an activity of 0.02×10^{-6} curie per kilogramme. If we take into account that the organism assimilates close to 50 per cent of the introduced strontium and that about 50 per cent of the assimilated strontium is fixed in the bones, we may assume that the skeleton received 5×10^{-9} curie per kilogramme, that is, by the end of the experiment the total activity in the bone skeleton did not exceed 3.7 microcuries per kilogramme. Under these conditions, two years later one could observe a considerably altered response of the organism to chemical substances and infectious toxins.

As A. V. Lebedinsky [47] remarks, observations in the Zakutinsky experiments lasted only 2.5 years, or one-sixth of the ordinary lifetime of the animal. It is natural to suppose that if the exposure is of longer duration (from 10 to 20 years and more in man), similar alterations will be observed even in the case of smaller doses of radioactive strontium.

Nervous Disorders

The large number of studies that have been conducted in the Soviet Union on the effects of ionizing radiation on the functional activity of the central nervous system (I. R. Tarkhanov, Y. I. Bakin, P. O. Kupalov, N. N. Livshits, M. I. Nemenov, M. N. Livanov, I. A. Piontkovsky, P. K. Lomonos, and many others [51]) permit us to agree with the thesis that the central nervous system (CNS) possesses considerable functional sensitivity to this kind of radiation. It has been definitely established that grave derangement occurs in conditioned reflex activity and in bioelectric activity of the cerebral cortex both in whole-body exposure and in localized irradiation of various divisions of the central nervous system. These alterations are of interest when analyzing the general course of radiation sickness, and should attract particular attention in studies of the effects of chronic exposure to relatively small doses of radiation. At a conference on medical radiology in 1956, Academician L. A. Orbeli placed special stress on the fact that if in the case of large doses of radiation the role of the central nervous system can, in large measure, be hidden behind intensely developing processes in all affected tissues and organs, in the case of small doses of radiation, the reaction of the CNS may be decisive, determining the biological response of the organism to these weak influences. A number of experimental studies corroborate this suggestion.

Radical derangement of the higher nervous activity was observed in dogs which had been exposed to chronic irradiation of the head with 10 roentgens per 24 hours (N. N. Livshits). In other experiments by him, the dogs received 25 roentgens six days a week for one month. No substantial alterations were observed in the functions of the blood system, though at the same time sharp disturbances were noted in the higher nervous activity. Disorders in conditioned reflexes appeared and disappeared in dogs

of the strong type, whereas in dogs of the weak type there was a general weakening of conditioned reflexes, and, in isolated instances, a derangement of differentiation. The weakening of conditioned reflexes set in before that of unconditioned reflexes [51].

The reaction of the cortex of the cerebral hemispheres to radiation is detectable in the case of very small doses. For example, Livanov [52] and Grigoriev [53] have shown that alterations in the rhythm and amplitude of bioelectric-potential vibrations of the brain set in after a dose of the order of one roentgen.

The introduction into the organism of radioactive substances has also caused functional disorders in the CNS. Serkov [54] made a study of the electrical activity of the cerebral cortex of persons that were given radioactive phosphorus therapeutically. Using a cathode-ray oscillograph it was established that several hours after 2 to 4 microcuries of phosphorus was taken orally, a substantial reduction in the electrical activity was observed. The amplitude of the alpha waves fell considerably, the alpha rhythm was not regular, and in some cases disappeared entirely. The response to light stimuli was weakened. In isolated cases, there appeared, along with a depression in the alpha activity in the electroencephalogram, slow irregular delta-type waves. In an experiment with cats, the action of the radioactive phosphorus was found to be of the double-phase type. The electric activity of the cortex became stronger in 10 to 15 minutes and reached a maximum in one hour. This high level was retained for several hours, after which a depression in electric activity set in.

The double-phase nature of the effects of radioactive phosphorus on the activity of the brain was also shown on dogs by means of conditioned reflex procedures. Using rats, Zyuzin [55] showed that the subcutaneous injection of 0.5-1 microcurie of radioactive phosphorus per 100 grammes of weight produced a marked effect on the origination and development of artificially induced convulsive

paroxysms. The anti-convulsive action becomes stronger 48 hours after injection, then slowly diminishes in strength, and disappears in 10 days.

A study conducted by Zyuzin on epileptics clearly showed the effect of small doses of radioactive isotopes (sodium-24, phosphorus-32, iodine-131) on the electric activity of the brain. For instance, 20 microcuries of phosphorus-32 administered orally was found to reduce the reactivity in one hour. There were hardly any explosions of epileptic discharges. Twenty-four hours later there was a sharp decline in the amplitudes of biocurrents and in reactivity to external light stimuli. Acute waves were practically non-existent.

Likewise in favour of the functional radiosensitivity of the nervous system are the investigations of Durmishyan [56], who has shown that the introduction into the blood stream of small quantities of radioactive sodium (Na^{24}Cl), which in six days produces a cumulative dose of 0.056 roentgen, alters the rate of passage of a nerve impulse through the synaptic junction of a reflex arc. It is interesting to note that repeated tests with the same animal exhibited an increase in the radiosensitivity to the same stimuli, which is suggestive of some sort of residual alterations even in the case of small doses of radiation.

Experimental data in favour of high radiosensitivity of the central nervous system is in agreement with clinical material taken from observations of patients that have received small doses of radiation for extended periods of time. Kovnatsky [57] has analyzed clinical material concerning persons in long contact with radioactive substances or exposed to radiation in dosages close to the maximum permissible; he points out that in chronic exposure to small doses of ionizing radiations the earliest changes are found in the central nervous system. These alterations find expression in the functional derangement of the central nervous system, which controls the general state of the organism. This derangement is frequently combined

with an asthenic state of the patient, who complains of sleepiness, weakness or quick fatigability and headaches. In addition to these subjective disorders, the patients are found to be inert and slow, to have pronounced dermographism, enhanced tendon reflexes, hyperhydrosis, and labile pulse and arterial pressure. Electroencephalography showed that only some of the patients had normal electroencephalograms. In half of the patients, the alpha rhythm was absent on the spontaneous electroencephalogram. Functional electroencephalography exhibited a sharp depression in the alpha rhythm in response to stimuli, and, in a number of cases, protracted afteraction. All these changes indicate a weakening of the principal processes in the cerebral cortex due to small long-continued doses of ionizing radiations.

Goryushin [58] who has analyzed extensive clinical material has come to the conclusion that in the case of the prolonged action on the organism of very small doses of incorporated emitters (occupational poisoning) the initial symptoms of the illness are alterations in the nervous system in the form of a neurasthenic type of neurosis.

It is difficult at present to give a quantitative assessment of the effects of enhanced radiation on the nervous activity of man. However, from the foregoing studies it follows that one may expect greater general fatigability, increased neurasthenic states, and weakening of the psychic activity of man.

The Genetic Effects of Radiation and Damage to the Immediate Descendants

Numerous investigations into the effects of radiation on the reproductive ability of animals, on the course of pregnancy and the further fate of offspring irradiated in the process of embryogenesis have shown that even relatively small doses of radiation are capable of causing

considerable deviations from the normal. Particularly sensitive are the female gonads. Studies by the Soviet scientists N. I. Nuzhdin, N. I. Shapiro and O. N. Petrova [59] have shown that irradiation of female mice with a 50-roentgen dose is sufficient to lead to radical disturbances in the oestrous cycle, while a decline in fertility is observed even for doses of 15 and 25 roentgens.

Reduced fertility is found to occur also in the offspring of irradiated animals, which is to say that it becomes hereditary.

The developing embryo is exceedingly sensitive to radiation. Investigations carried out with comparatively large dosages of radiation (100 to 200 roentgens) have shown the radiosensitivity to vary sharply at different stages of the embryonal development. It has been shown [59a] that irradiation during the early stages of pregnancy results mainly in the death of the embryo in the process of embryogenesis.

Irradiation during the period of basic organogenesis, that is, when the organs and tissues in the body of the embryo become established and differentiated, as a rule leads to deformities. Deformities appear with particular ease during formation of the central nervous system. There is still insufficient material to show the effects of irradiation during embryogenesis in humans; however, available observations in Hiroshima indicate a considerable increase in the percentage of stillbirths, deformities, reduced weight of the new-born children and their retarded development [60].

To make the problem of the genetic damage to man from the increasing radioactive background easier to understand, I give in brief and schematic outline the basic principles of genetics—the science of heredity.

It is common knowledge that the human organism, like that of any living organism, develops from a single cell—the fertilized ovum. The germ cells—the ovum and the spermatozoon—differ from all other cells of the organism

in the structure of the nucleus. The nuclei of all cells in man contain 48 structures, called chromosomes, that are visible in the microscope. Each chromosome has a similar partner chromosome. Of the 24 pairs, each is morphologically somewhat different from all the rest. The chromosomes of nuclei are built up from protein substances—desoxyribonucleoproteins (DNP). It should be stressed that if all the substances that participate in the construction and functioning of the living organism are arranged in a sequence of structural complexity and the possibility of taking on various configurations, the substance that would crown this sequence is precisely desoxyribonucleoprotein—a constituent of the chromosome.

Before division of a cell, there occurs intense synthesis of the DNP of the chromosomes; each chromosome doubles its size and divides, giving birth to two absolutely identical chromosomes. Each of these moves to the different poles of the cell, and, after division, both daughter cells contain the same 48 chromosomes that were in the mother cell. An important point is that when the cell divides, the cytoplasm and other inclusions within it (mitochondria, microsomes, and protoplasts) partly pass into one cell and partly into the other. It frequently happens that one of the daughter cells is quite a bit smaller than the other, and, consequently, there is even a quantitatively non-uniform distribution of cytoplasm and its inclusions between the daughter cells. In normal division, it is only the nuclear matter that undergoes the characteristic doubling and is evenly distributed between the daughter cells.

Duplication of chromosomes does not occur in the formation of the germ cells; the 24 pairs of chromosomes separate towards the poles, and after division there are only 24 chromosomes in each germ cell. When fertilization takes place, the spermatozoon with its 24 father chromosomes penetrates into the ovum, which has 24 chromosomes from the mother organism. The nuclei of the spermatozoon and the ovum fuse to form the nucleus of the ferti-

lized ovum, now containing a normal complement of 48 chromosomes.

The principal task of genetics is to get to understand why outwardly almost identical embryonic cells develop into a very specific organism and why the ovule of a definite species always develops into an organism of the same species: the human ovule gives rise to man, that of a monkey becomes a monkey, the ovule of a horse develops into a horse, etc. Another thing that must be understood is why the organism that develops is sometimes a very close copy of the father organism, and sometimes of the mother, sometimes with features of the grandfather or great-grandfather, and sometimes a combination of the features of its parents. If, as we occasionally hear, the son and father are as like as two peas, it is obvious that the cause is to be sought in the nature of the spermatozoon, which in fertilization entered the ovum from the father organism. Besides the plasma elements of the spermatozoon, an essential role in the transfer of hereditary properties will be played by the complex molecules of DNP of the nucleus of the spermatozoon.

The highly polymerized molecules of DNP are made up of desoxyribonucleic acid and protein. Both of these substances are polymers, with an infinitely varying structure. Desoxyribonucleic acid (DNA) has a molecular weight of the order of three million and is in the shape of a long spiral-like coiled chain consisting of many hundreds of nucleotides. We find DNA to be composed of four structurally different nucleotides. In the building up of the long chain of DNA, these four nucleotides can arrange themselves in the most diverse sequences. The possible number of arrangements is stupendous—exceeding by far the number of all the species and varieties of living beings on earth.

In the DNP, the desoxyribonucleic acid is combined with protein. As we know, protein is likewise a high-molecular-weight substance (molecular weights: 70-300 thou-

sand) and is composed of at least 20 different amino acids. These different amino acids combine in various sequences and can also yield an almost limitless diversity of fine structure in the protein molecule.

A nucleoprotein is a system of two infinitely varying polymers. In the process of evolution, each species has evolved its own, characteristic desoxyribonucleoprotein. DNP, like thousands of other substances that comprise the organism, is constantly being broken down and rebuilt anew, that is to say, it participates in metabolism. But by virtue of the general structure of the living being, by virtue of the existence of specific macro-, micro-, and sub-microscopic structures that organize and direct the biochemical processes of metabolism, our organism is constantly regenerating not accidental substances but strictly specific substances peculiar to it.

Idealists in philosophy have tried to attribute very peculiar properties to this substance. Some of the attributes have been: the mysterious property of self-reproduction (reduplication), an independent existence in the cell, and peculiar stability and invariability with respect to changing conditions of the environment. DNP does not possess any of these properties. On the contrary, it is very unstable, easily decomposes, actively participates in the general metabolism and, undoubtedly varies with changes in the environmental conditions of the organism, which fact permits the organism to become adapted to its environment and to develop in the process of evolution.

However, just as in the green leaves of plants there are synthesized—due to a specific coordination in the functioning of the many enzymic systems that have historically evolved—molecules of chlorophyll of highly complex structure that always reproduce one another exactly, so also—due to the same general laws of metabolism—there are built up new molecules of DNP, which reproduce identically the structures that existed in the given cell before. Each substance that is created in the living cell has

strictly definite functions. Chlorophyll conditions photosynthesis, flavines take part in the transfer of hydrogen in oxidation-reduction reactions, vitamin B₁ goes to build up cocarboxylases and accelerates the decomposition of ketocarboxylic acids, etc. In exactly the same way, DNP has the most complex and responsible function in the cell—that of directing and regulating a series of synthetic processes essential for its development.

At present, the main stages of this influence of DNP have been clarified. In accordance with its structure, another nucleic acid in the nucleolus of the cell—ribonucleic (RNA)—is synthesized. RNA carries the information received from DNP to the cytoplasm. In accordance with the specific structure of RNA, specific protein substances (peculiar only to the given species), including also numerous protein enzymes, are synthesized in the mitochondria and microsomes. Apparently, the system of protein enzymes determines the syntheses of other substances, and also the harmonized processes of metabolism that lead to the formation of definite structures in the developing organism. It would appear that each pair of chromosomes has its own structural versions of DNP that condition the development of definite systems in the cell and cell differentiation in the process of development of the organism. The great complexity and variability in the structure of the macromolecules of DNP permits of the assumption that there is a very large number of types of molecules within the framework of the general structure peculiar to the given species. This possibility allows for controlling many hundreds of processes that occur in a living cell. If in a living cell some structural type of DNP were destroyed, this would mean depriving the cell of the specific capability of effecting a given process.

In division, the chromosomes with the altered set of DNP would transmit this defect to the daughter cells. If it affects the vital processes, the organism will not be able to develop. If it is of a secondary nature, the developing

organism will be deprived of a definite function. The result will be a deformity, an abnormality in the vital activities, or a new variety. Such a deviation from the normal has become known as a mutation. Mutations result from alterations in the nuclear matter and are transmitted hereditarily.

In nature, alterations in DNP ordinarily appear both due to the effects of the natural background radiation and due to other causes that give rise to mutations. Many of them are not viable; they are the underlying cause of a certain percentage of stillbirths. Others lead to deformities and a series of hereditary diseases. (Of course, both stillbirths and deformities can be traced to other causes not connected with changes in the DNP.)

In man, typical manifestations of damage to the nuclear matter (DNP) are such illnesses as microphthalmos, haemophilia, retinoblastoma, schizophrenia, microcephaly, albinism and others. The frequency of many hereditary diseases is very low, of the order of 10^{-5} per generation.

At present, many factors are known which are capable of upsetting the normal structure of DNP in the nuclei of germ cells and, in this way, of increasing the mutation rate leading to the death of the offspring or to the appearance of deformities and hereditary diseases. Some chemical substances that react with DNP have this property.

And the same is true of radioactive radiations. For the first time, the mutational action of radium rays was discovered in 1925 by the Russian scientists G. A. Nadson and G. S. Filippov.

In 1927, the American scientist H. J. Muller reported the possibility of mutations being induced by ionizing radiation. Irradiation ordinarily gives rise to the very same aberrations that appear spontaneously, only the frequency is increased. Numerous investigations carried out on plants, insects, and small animals [61] have shown that *the frequency with which mutations appear is directly proportional to the total dose of radiation.*

Consequently, any increase in the natural radioactive background leads to a corresponding increase of deleterious (as a rule) mutations, that is, to an increase in the number of stillbirths, deformities and hereditary diseases.

Doubtlessly, a part of the hereditary diseases that appear is due to the natural background radiation. For further quantitative forecasts, it would be very important to know just what portion of the total this is. However, it is here that the opinions of investigators differ. The well-known English geneticist, Haldane, admits that in man and, maybe, in other relatively long-lived species, the natural mutation rate is totally due to the natural level of radiation. Another no less authoritative scientist, the American geneticist Muller, arrives at the conclusion that only 5 per cent of all natural mutations is due to the natural radioactive background. What is the normal irradiation dosage that the germ cells of man receive?

Below is some information on the irradiation dose to the human gonads in localities with normal natural radioactivity [62].

Radiation source	Dose to gonads per year (rad)
External irradiation	
Cosmic rays (sea level)	0.028
Local gamma rays (from natural radio- elements)	0.043
Radon in air, 3×10^{-13} curie per litre	0.001
Internal irradiation	
Potassium-40	0.020
Carbon-14	0.001
Radon and disintegration products, 3×10^{-13} curie per litre	0.002
Total dose per year	0.095
Dose to age 30 years	2.85

Of course, this average dose will vary considerably depending on the conditions of life. The calculations of

Swedish scientists [63] have revealed the following variations of irradiation of the gonads by gamma rays (with the exception of cosmic radiation) depending on the material from which dwelling houses are made:

Building material	Dose to gonads, roentgens in 30 years
Wood	1.0
Brick	2.0
Concrete	3.2

Table 12 summarizes the data on the principal variations in irradiation of the gonads taken from large segments of the population [64].

From these data it follows that, on an average, natural radiation gives to the gonads a dose of 3 to 4 rems in 30 years. According to the estimates of Muller, a double mutation rate affecting the entire population may prove fatal to humanity. Quite natural, therefore, is the interest in this so-called "doubling dose," a doubling of the mutation rate.

Haldane takes the stand that this is a dose of 3 to 4 rems. If we take Muller's calculations, the doubling dose for mutations is

$$\frac{(3-4) \times 100}{5} = 60-80 \text{ rems.}$$

Attempts have been made to determine this doubling dose experimentally on plants, insects and animals. The results are given in Table 13.

Later investigations carried out on more extensive material [74] have shown greater radiosensitivity of the gonads of the mouse as compared with those of *Drosophila*, which has enabled us to take 30 rems as the most reliable figure. Studies by Soviet scientists [75] carried out on monkeys have yielded a still higher radiosensitivity of the gonads of these animals as compared with mice. These data have led the Soviet geneticist Dubinin [76] to the conclusion that for man we should take a doubling

Table 12

**Estimated Values for the Irradiation of the Gonads of the
Population due to Natural Sources in rems per 30 Years**

Radiation source	Radiation dose to gonads		
	Minimum	Maximum	Average
Cosmic radiation	0.7	3?, about 4,000 m. above sea level	1?
Natural radiation: ¹ / ₄ of 30 years out of doors .	0.1, above water (in boats), snow and ice	1, above igneous rocks	0.5
³ / ₄ of 30 years indoors . . .	0.9, wooden houses	3, in some types of brick and concrete houses	2
Radon in air .	0.03, out of doors and in wooden houses with good ventilation	0.8, in cellars and stone houses with poor ventilation	0.2
Potassium-40 in body (+0.03 for C ¹⁴):			
Fat . . .	0.2	0.2	0.2
Muscles . .	0.7	0.7	0.7
Gonads . .	0.5	0.5	0.5
Approximate sum for gonads .	2	6 (8?)	4

Table 13

Doses That Double the Frequency of Mutations

Group	Species	Irradiated object	Doubling dose, r	Source
Plants	Maize	Pollen	28	[66]
	Oenothera	"	60	[67]
	Sweet cherry	"	60	[68]
Insects	Drosophila	Spermatozoa	50	[69]
	"	"	60	[70]
Mammals	Mouse	Spermatogonia	50	[71]
	"	"	50	[72]
	"	"	30	[73]

dose of 10 rems. The United Nations Scientific Committee, which made a special study of the problem of the effects of radiation on man, has also taken 10 rems as a probable doubling dose for man. Of course, 10 rems will double the number of mutations only on the condition that the radiation is received by large groups of the population.*

Let us try to calculate the genetic damage to mankind as a result of nuclear tests in the event that they are not stopped.

Statistical investigations have shown that from 1 to 4 per cent of all children are born with hereditary diseases. Therefore, if the world's population receives a doubling dose of radiation (to the gonads), it will lead to another 1 to 4 per cent of damage. If we take the mean age for man at 60 years and assume that the average reproductive span is 30 years, then in one generation (30 years) there will be born

$$\frac{P \times 30}{60} = \frac{P}{2} \text{ persons,}$$

where P is the total world population. The number afflicted with hereditary diseases will be (at a maximum) $\frac{4 \times P}{100 \times 2}$.

If we take the doubling dose as equal to 10 rems, then for every rem of irradiation the number of afflicted will be one-tenth, that is, equal to $\frac{4 \times P}{100 \times 10 \times 2}$. Now if we multiply this figure by the dose which the gonads receive in 30 years from radioactive fall-out— D_{30} —we obtain the total number of persons afflicted in one generation:

$$\frac{D_{30} \times 4 \times P}{100 \times 10 \times 2}.$$

* Irradiation of individuals or even of comparatively big groups of persons (for example, employed in specialized jobs) with appreciably larger doses cannot produce essential genetic damage because marriage between irradiated persons and non-irradiated (the bulk of the population) quickly reduces the probability of hereditary alterations.

For one year, naturally, the figure will be less by thirty times.

What will D_{30} be if the testing continues? Irradiation of the gonads will mainly be due to the gamma radiation of cesium-137. The gonad dose can be calculated from the following formula:

$$D_{30} (K_1 \times C \times E \times F_1 + F_2) \times 30,$$

where K_1 is the amount of radiation from 1 mc/km² per year, taken to be equal to 0.08 mrem per year;

C is the attenuation of the gonad irradiation due to absorption by the body tissues (close to 0.6);

E is the protective action of buildings; on an average, it can be taken at 0.3, considering that large groups of the population spend a substantial part of their lives out of doors;

F_1 is contamination by cesium-137, millicuries per sq.km. It can be taken as equal to strontium-90 contamination, that is, roughly 270 for the equilibrium period;

F_2 is the gonad dose from cesium inside the body. Measurements in 1957 showed that the human body contains about 50 micromicrocuries of cesium per gramme of potassium; this produces an annual gonad dose of approximately 1 mrem. Although there will be a 60-fold increase in the contamination of the environment by the time equilibrium has been established, it will not bring about a corresponding increase of cesium content in the organism due to poor exchange of this element between the soil and the body. However, there can be no doubt that such an increase will occur later on. Even if we assume in this case a discrimination factor of 0.1, we can expect an increase in the gonad dose from internal radiation due to radioactive cesium up to 6 mrems per year.

Thus, the cumulative gonad dose for 30 years up to the time of an established equilibrium will come out to:

$$D_{30} (0.08 \times 0.6 \times 0.3 \times 270 + 6) 30 = 296 \text{ mrems,} \\ \text{or } 0.29 \text{ rem.}$$

If we take the world's population for the time of established equilibrium at 5×10^9 , it is easy to compute the total number of persons afflicted with hereditary diseases from cesium fall-out per year:

$$N_y = \frac{4 \times 0.29 \times 5 \times 10^9}{100 \times 10 \times 2 \times 30} = 96,000 \text{ persons.}$$

This means that if nuclear weapons tests are not stopped, there will be (by the beginning of next century) 96,000 children born annually afflicted with such grave hereditary defects as deformities, mental retardation, haemophilias, microcephalies, etc.

It must be stressed that this is not yet the highest figure. We do not as yet know exactly the radiosensitivity of the human gonads, we do not know just what changes occur in the chromosomes due to radioactive strontium entering them directly, and there are still hazy notions concerning the effects of tropospheric fall-out, which occasionally is very considerable. In our calculations we took the doubling dose at 10, and not at 3, as Haldane suggests. If it is three, the damage will be three times greater. Such is the genetic injury due to nuclear testing.

If we add up the damage to mankind (for the beginning of next century) in the form of leukemia, bone cancer and hereditary diseases, we get the enormous figure of $218,000 + 40,000 + 96,000 = 354,000$ persons.

350,000 every year, or about 10,000,000 human lives in one generation (30 years)—such is the horrifying price that man will pay if he does not stop nuclear weapons testing at once.

X. SCIENTISTS THE WORLD OVER SPEAK ON THE DANGER OF NUCLEAR WEAPONS TESTING

The atom bombings of Nagasaki and Hiroshima, the ground and underwater bursts in the Pacific Ocean, and the high-yield hydrogen bomb explosions in 1954 have posed to humanity as a whole and first of all to the scientists of

the world the ominous question: where are people being led by such terrible toying with this new force that is capable of destroying the entire cultural world and of wiping off the face of the earth all living beings. The best minds of the world, who have put so much labour into explorations into the secrets of the structure of the atom, into studying its properties and the possibilities of utilizing the enormous reserves of energy locked up within it, now look in horror as they see their bold dreams transformed into a reality that sows fear and threatens to leave in its wake colossal destruction and death instead of being turned to better the conditions of human life. The scientists that discovered the new, atomic, energy could not but realize that they were bringing to people a great danger. That which could be utilized to benefit humanity to an unthinkable degree, is being used chiefly to prepare a new and destructive war that would bring mankind incalculable distress and misery.

The first voice was that of the greatest physicist of our century, Albert Einstein. On his initiative ardently supported by the English philosopher Bertrand Russel and the French physicist Frédéric Joliot-Curie, a statement was published by ten scientists warning the world of the danger that threatens mankind from the possible use of atomic energy for purposes of war.

Albert Einstein appealed to the scientists of the whole world to determine with scientific competence the true proportions of the danger and to make these facts known to the public.

In August of 1955, Bertrand Russel organized in London an exchange of opinions between scientists and political leaders of different countries on questions of the hazard to humanity from nuclear weapons testing and from a future atomic war. This meeting was attended by: Prof. B. Russel, Prof. J. Bernal (physicist), Prof. F. Gregory (plant physiologist), Prof. A. Haddow (pathologist), Prof. H. Jones (physicist), Prof. C. F. Powell (physicist), Prof.

J. Rotblat (physicist), Prof. C. H. Waddington (geneticist), Prof. V. Levitt (physiologist) from Great Britain; Prof. P. Harnham (parasitologist), Prof. A. M. B. Lacasagne (radiobiologist), Prof. S. N. Martin (physicist) from France; Prof. E. Rabinowitch (biologist) from the U.S.A.; Academician A. Topchiev (chemist), Corresponding Member of the U.S.S.R. Academy of Sciences, M. Markov (physicist), Prof. A. Golunsky (lawyer), and Prof. A. Kuzin (radiobiologist) from the U.S.S.R.; Prof. M. Oliphant (physicist) from Australia; Prof. J. de Castro (physiologist) from Brazil; Prof. W. Isaac (botanist) and Dr. E. Leisegand from South Africa; Prof. T. Sekhadri (chemist) and Dr. U. Pavri from India; Prof. S. Stanković from Yugoslavia and others.

Despite the extreme diversity in political views and convictions, the scientists of different countries came to a single opinion on the responsibility of men of science for the distress that an atomic war can bring to humanity, and on the necessity to warn the governments of all countries concerning the imminent danger. The unanimously adopted resolution stressed the fact that the use of atomic energy for war will inflict untold misery on humanity, that scientists must investigate the extent of the danger from atomic tests both as regards the present generation and its descendants, and that the sacred duty of all scientists is to struggle for a utilization of their discoveries for the benefit of the people and not for destruction and death in future wars.

There was universal response to this appeal in the broadest scientific circles. Four hundred Japanese scientists brought out a statement on the necessity of stopping nuclear tests immediately. The Japanese scientists wrote on the basis of their studies of the effects of the atomic bombings of Nagasaki and Hiroshima, and of contamination of the Pacific Ocean area with radioactive uranium fission-products following the explosions at Bikini and Eniwetok. As representatives of the nation that suffered most

from atomic explosions, the Japanese scientists pointed to the great danger to future generations from the continuing test explosions of nuclear bombs. They spoke of the necessity of stopping at once these explosions that bring to our children thousands of cases of disease, of the necessity of prohibiting the use of atomic weapons, they spoke of the horrible misery that awaits mankind if an atomic war is unleashed.

In April 1957, a statement was published by 18 prominent German scientists—specialists in the field of nuclear physics. They included such well-known men of science as the Nobel Prize winners Max Born, Otto Hahn, Werner Heisenberg and Max von Laue. Among the signatories were Otto Hahn and Fritz Strassman—discoverers of the fission of uranium that served as the starting point in the development of atomic energy.

In their statement, the German scientists stressed the point that so-called “tactical” atomic bombs are ordinary atomic bombs similar to those that devastated Hiroshima and Nagasaki. A single “tactical” atom bomb is capable of totally destroying a small-sized town. And a modern hydrogen bomb can make uninhabitable a big industrial region the size of the Ruhr. The entire population of the German Federal Republic can be wiped out by the radioactivity from hydrogen bombs. The German scientists said: “We do not know of any practical possibility of protecting the population from this hazard. The only way is to eliminate atomic warfare as a means to the solution of contradictions.”

The scientists added that they “... refuse to participate in the production, testing and use of atomic weapons. Scientists must work only on the peaceful utilization of atomic energy.”

The World Federation of Scientists has made an appeal to stop the testing of atomic and hydrogen bombs as a first step to the conclusion of an agreement on the prohibition of atomic weapons and the reduction of armaments.

One of the greatest French scientists, the physicist Frédéric Joliot-Curie, who discovered artificial radioactivity and did a great deal of research in the field of nuclear physics, wrote in 1957: "We know that the danger is a real one, and we must tirelessly sound the alarm, we must not let the peoples get used to the terrible danger that awaits them..." Joliot-Curie points out that "... if the continuing test explosions are not stopped the quantity of radioactive strontium in the bodies of people, especially children during their growth period, will definitely reach a level at which there can arise numerous cases of malignant tumours of the bone and leukemia..."

An ardent appeal to the whole world calling for immediate cessation of nuclear tests was made by the prominent Swiss philosopher-scientist Albert Schweitzer.

Basing his views on the results of research carried out during recent years, Schweitzer places particular emphasis on the hazard of accumulating radioactive strontium in the human body and the environment. He refers to investigations on the content of radioactive fission products in the Columbia river in North America. Though the water itself contained infinitesimal traces of radioactivity, it was found that the river plankton was 2,000 times more active than the river water. In this region, ducks that fed on the plankton were from 15,000 to 40,000 times more radioactive. Young swallows that fed on the insects that inhabit the river were radioactive to the extent of 500,000 times that of the river water, while the yolks of the eggs of water birds were more active by a factor of one million. Such is the ability of living organisms to concentrate radioactive substances that appear in nature in the most minute quantities. Taking into account this accumulation and the property of radioactive strontium to concentrate in the human bones, Schweitzer stresses the danger that awaits our children from the increasing incidence of leukemia, bone cancer and hereditary diseases. Again, he emphasizes the fact that the cumulative increase in radioactive ele-

ments in the body can be calamitous to the human race, that what confronts us is a danger which, though not fully understood as yet, is frightening. Only immediate cessation of nuclear weapons testing can prevent oncoming disaster—this is how Schweitzer concludes his appeal.

The views expressed by Joliot-Curie, Bernal, Schweitzer and others have found a broad response among many scientists. Two hundred and thirty scientists of France and two hundred and fifty-six from Great Britain have spoken in favour of immediate suspension of atomic weapons tests.

When certain official representatives of American science, like Libby, for example, came out in the press with statements about the harmlessness of nuclear tests, these statements were met with indignation not only by the majority of scientists in all other countries, but also by the major part of the American scientists. The American Federation of Scientists—on behalf of its 2,500 members—published a statement criticizing the main points of Libby's view and pointing out the urgency of putting an end to the further testing of nuclear weapons.

During the 12 years since the first atomic bomb explosion, over one hundred bombs have been detonated. Over 40 explosions have been recorded since January 1, 1956 (this is as of 1959). If we take into consideration the yields of individual bombs, we may estimate that the total energy released and, therefore, the radioactive fission products amount to some 6-7 thousand atomic bombs of the type dropped on Hiroshima and Nagasaki. It is clear, then, why scientists speak of the danger of continuing tests.

The French atomic scientist Charles Noel Martin has said that "... every scientist worthy of the title is duty bound to explain to all people the danger that confronts us..."

The Japanese scientist Kusano has made a special study of the effects of radioactivity on the human organism in Hiroshima and Nagasaki. He writes: "... in 10 years the quantity of strontium-90 radioactivity that will have fallen

out will reach a maximum permissible level for man. Test explosions must be stopped immediately. To do this, we must have negotiations at once...."

Prof. Charles Alfred Coulson, the outstanding British mathematician and physicist, of Oxford University, relates that many British scientists are engaged in the study of radioactivity effects produced by the testing of hydrogen bombs, and the consequences that would follow from the use of these bombs in a war. Coulson shows how justified are the apprehensions for man's health if the tests continue. He points to definite signs of damage that has already been inflicted and that will increase considerably within the coming ten years. If in the coming ten years the tests continue at the present rate, writes Coulson, man will suffer gravely and his future may even be endangered.

Discontinuance of further test explosions, he adds, would be a realization of our responsibility to humanity. Someone has got to take the first step. This done, the atmosphere of mutual trust, at present blighted, could be more easily restored. As a Christian he believes that such a campaign should be regarded as a sacred duty.

František Běhounek, professor of Charles University in Prague (Czechoslovakia), has spent many years studying radioactive radiations and their application in geophysics and medicine. He writes: "We do not know what the rate of atomic weapons testing will be in the future. It has not been definitely established how much strontium-90 has been injected into the stratosphere as a result of previous tests." Touching on possible baneful effects, Professor Běhounek stresses first of all the genetic damage, and explicitly demands "an immediate stop to the testing of atomic weapons, and their prohibition."

At a conference of French scientists and physicians in Paris, May 25, 1957, Professor Jean Bernard pointed out that in Japanese villages that suffered from atomic bombing, the incidence of leukemia was from 7 to 10 times higher than in unaffected areas. Professor Tlubiana dwelt on

the ability of radiation to cause cancer and shorten the length of life. Professor Bugnard, Director of the National Institute of Hygiene, said that although atomic tests represented a definite hazard, this threat was as nothing compared with the danger of an atomic war.

Speaking of the influence of radiation on heredity, the well-known radiologist Professor Lacassagne underlined the point that all ionization of cells is detrimental. Even a single exposure of the chromosomes can give rise to irreversible changes in offspring.

According to Professor Turpin, at the present rate of radioactivity increase the number of catastrophic mutations can double in a single generation. The result will be twice as many blind persons, idiots, haemophilia sufferers, etc.

On April 2, 1957, following speeches by John Bernal and others, the Bureau of the World Peace Council approved an appeal, which in part says that "... continued testing can affect the health and lives of several generations and, particularly, of children. ...

"We demand immediate agreement on a suspension of these tests. This will permit safeguarding the lives of our children. ..."

At the Colombo session of the World Peace Council (June 10-16, 1957) where the delegates of 70 countries were gathered, an appeal was made to all governments of the world on the immediate suspension of nuclear explosions. It reads:

"Scientists of high authority in all countries, feeling their responsibility as citizens, are warning humanity of the unaccountable misfortunes which threaten present and future generations if nuclear weapon tests are continued. The conscience of mankind demands that these tests be stopped. It lies on the conscience of all who care for the destiny of mankind to join in the common effort to achieve this aim."

On April 26, 1957, the Scientific Council of Japan (its president is Kaya Seidzi) appealed to the scientists of the

whole world on the cessation of nuclear weapons testing. The appeal reads:

"We scientists are aware of the deleterious effects of radioactive debris, which falls out from explosions of nuclear substances, on people the world over and on future generations no matter in what part of the globe the shots are fired.

"We shall do everything in our power as scientists to avert these consequences by means of research and enlightenment of the public.

"We again appeal to the scientists of the whole world to cooperate in this problem."

Through the initiative of Lord Russel and the generous hospitality of Mr. Cyrus Eaton, the American industrialist, a conference of independent scientists was held in July of 1957 to discuss the hazard that confronts mankind in the form of nuclear weapons testing.

The conference took place in Nova Scotia (Canada) in the fishing village of Pugwash with twenty-two prominent scientists from ten different countries participating. Among them were Nobel Prize winner, Prof. C. F. Powell (physics) and Prof. J. Rotblat from Great Britain; the prominent radiobiologist, Prof. A. M. B. Lacassagne from France; Prof. P. Doty (chemistry), Nobel Prize winner, Prof. H. J. Muller (genetics), Prof. E. Rabinowitch (biology), Prof. W. Selove (physics), and Prof. Weisskopf (physics) of the U.S.A.; Nobel Prize winner, Prof. H. Yukawa (physics), and professors S. Tomonaga and I. Ogawa from Japan; Prof. Chou Pei Yuan, of Peking University, from the Chinese People's Republic; Prof. John S. Foster (physics), Dr. G. Brock Chisholm from Canada; Prof. M. L. E. Oliphant (physics) from Australia; Prof. H. Thirring (physics) from Austria; Prof. M. Danysz from Poland; Academician A. V. Topchiev (chemistry), Academician D. V. Skobeltsyn (physics) and Prof. A. M. Kuzin (radiobiology) from the U.S.S.R.

The conference discussed with all seriousness the ex-

tent of the hazard due to the build-up of strontium-90 and cesium-137 contamination and the problem of the responsibility of scientists to the public at large for the consequences of the use of atomic weapons. It should be pointed out that this was the first time that such questions were discussed between scientists of the capitalist countries and of the socialist world. Despite differing political convictions and views as to the future development of society, all the scientists completed the discussions with a single opinion on the degree of harm to the population from the tests of nuclear weapons. It was noted that current testing will produce, within coming decades, 100,000 cases of leukemia and bone cancer, and will give rise to approximately as many cases of grave hereditary diseases. The participants of the Pugwash conference placed particular stress on the fact that an atomic war any place in the world would have devastating effects on all of humanity due to the rapid build-up of radioactivity over the globe and the mass-scale fall-out of radioactive debris.

Speeches by the Soviet representative (A. M. Kuzin), a Japanese scientist (S. Tomonaga) and an American representative (W. Selove) criticized the view taken by W. Libby on the harmlessness of the present nuclear weapons testing.

By far not all people are aware of just what a catastrophe for mankind an atomic war would be. This is why the participants of the Pugwash meeting came to the common conviction that it is the direct duty of scientists to do everything in their power to avert war, and to further the establishment of a permanent and general peace.

Scientists are better aware of the terribly devastating force of the atomic weapon, and they, better than anyone else, know the tremendous advantages that accrue to humanity in the peaceful utilization of atomic energy. Scientists must inform every single person of the unthinkable consequences of atomic weapons put to use.

The work of the scientists was given good coverage in the press. *The New York Times* of July 12, 1957, said of the Pugwash conference that the scientists of ten countries, on the basis of data obtained from studying the effects of atomic weapons testing, have come to the "unquestioned conclusion" that unrestricted nuclear warfare would represent a "disaster of unprecedented magnitude," and that there is very little hope that once a nuclear war begins it will be confined to a small area.

Wrote the *Montreal Star* of July 12, 1957: "Scientists said the great nations should develop an international system of controls to avert a world war and added suspension of nuclear tests would be a good first step in this direction.

"... Measures urged included lessening of tensions, an end to the arms race, provision of safeguards in the arms control system to build confidence and initiation of a process to develop a practicable set of controls."

The Pugwash resolution reads: "We are all convinced that mankind must abolish war or suffer catastrophe."

In another article, *The New York Times* (July 11, 1957) quotes Prof. Rotblat, of the University of London, as saying that "a little publicized effect of fall-out radiation and that of related character (such as X-rays) is its shortening of the length of life." The article goes on to say that "in a statement to the conference, he said that persons exposed to 300 roentgen units over a period of months or years as could happen in a fall-out region, might have their lives shortened by as much as four years."

A detailed report on the Pugwash conference was given by the British scientific journal *Nature* (No. 180, 1957, p. 358). In part it says: "The committee on the hazards associated with the application of atomic energy found that estimates of the effect of 'fall-out,' carried out independently in Great Britain, Japan, the United States and the U.S.S.R., were in good agreement; it reached the conclusion that the dangers from the test explosions carried out hith-

erto are small compared with those to which mankind is subject from natural causes. Nevertheless, because of the world-wide distribution of fission products, and the fact that some areas may be subject to effects much above the average, close attention to the dangers should be maintained, especially if tests of bombs which give large radioactive 'fall-out' continue to be made."

On August 13, 1957, a large group of Soviet scientists published the following statement:

"At a time so tense and fraught with the danger of an all-out war of destruction, scientists cannot stand aloof. Their duty is to add their voices to the demands for a suspension of nuclear weapons testing. . . . It is urgently necessary that scientists throughout the world give warning to all about the true proportions of the approaching danger that threatens the health of both present and future generations of man."

In their statement, the Soviet scientists support the proposal of the Pugwash conference to call together a broad meeting of the most prominent representatives of science from all countries to join efforts in the struggle for immediate prohibition of nuclear weapons and their tests and to avert war. The statement was signed by the President of the U.S.S.R. Academy of Sciences, Academician A. N. Nesmeyanov, the Vice-President, Academician A. V. Topchiev, Nobel Prize winner, Academician N. N. Semyonov, Academicians P. L. Kapitsa (physics) and D. V. Skobeltsyn (physics), President of the Ukrainian Academy of Sciences, A. V. Palladin, Academician E. N. Pavlovsky (zoology), Academician A. I. Oparin (biochemistry), and many others, making a total of 198 scientists.

The scientists of Leningrad met on August 16, 1957 to raise their voices in protest against the use of atomic energy for purposes of war. The well-known physiologist, Academician K. M. Bykov said: "We have gathered here today with feelings of extreme responsibility and profound con-

cern for the fate of man to protect again and again and, maybe, more strongly than ever the future of humanity.

"For us, scientists of different specialities, it is a sacred duty to protest and to fight to the last against atomic energy being used militarily. . . .

"On the basis of precise scientific materials, with complete frankness and without exaggerating the least bit, I, as a physiologist, must give warning of the grave consequences to the health even of a person who is not directly in the area of the atomic explosion. . . ."

In their speeches, Academicians L. A. Orbeli and A. F. Yoffe and many others stressed the necessity to achieve agreement on immediate suspension of nuclear weapons tests, on the reduction of arms, and the prohibition of atomic warfare.

We see that the scientists of the entire world—Japan, the United States of America, Great Britain and France, Western Germany and the Soviet Union, Czechoslovakia and Australia, Canada and Switzerland, and many other countries are at one in their conviction of the dangers to humanity of the testing of nuclear weapons. Strangely discordant are the isolated voices of those American scientists that are closely connected with circles which are directly inspiring the atomic arms race and who maintain that the tests are harmless and need to be continued. First among them is W. Libby, who has expressed such views in newspaper articles and interviews. And then there are Teller and Latter who published a whole book to this effect—*Our Nuclear Future* [33].

What reasoning underlies the views of these scientists? How do Libby, Teller and Latter and their like approach the public to convince it of the harmlessness of continued nuclear testing?

The first and crudest procedure is simply to conceal the true proportions of this hazard. In their calculations they begin with incorrect data—optimum conditions and the biggest discrimination factors; and, often taking advan-

tage of our approximate knowledge, they palm off the minimum version as the only possible one. To take an example, Teller, both in *Our Nuclear Future* and in *Life* magazine (Feb. 10, 1958), maintains that in the case of continued testing the radiation intensity to bone will increase fivefold. This is absolutely incorrect and runs counter to up-to-date scientific findings. (J. L. Kulp [77] mentions a 25-fold increase for children and a 167-fold increase for adults. As has already been shown, a still greater increase is possible.)

Again incorrect is the current radiation dose to the bones of children—0.002 roentgen per year—that Teller gives in Chapter XII of his book. It is well known that the amount of strontium in the bones of children reaches 2 to 4 strontium units. In a year, one unit produces 2.7 mrad, which means that the current irradiation lies within the range of 0.005 to 0.01, and not 0.002 as Teller writes without giving any proof.

As L. Pauling [78] has shown, Libby and Teller have resorted to downright distortion of the facts in an attempt to prove that irradiation of the gonads from a luminous watch is ten times as dangerous as the radiation from radioactive fall-out.

In their calculations, Libby and Teller took the radium content in the watch at 1 microcurie, and the distance from the source to the gonads, 1 foot. The starting point was the assumption that the watch is worn for a lifetime and 24 hours a day; in addition, since it was a comparison of genetic injury, it was tacitly assumed that the whole population wears luminous watches. Not a single one of these assumptions is correct. A watch has only 0.2 microcurie of radium; the distance of the source from the gonads is an average of 16 to 18 inches; watches are worn not 24 hours a day and not one's whole lifetime; finally, not every person wears a luminous watch, but only some 3 per cent of the world's population. Consequently, Teller's figure of 0.03 roentgen per year for the entire population

is in fact only 0.00006 roentgen, or less by a factor of 500. The radiation from radioactive fall-out is not less than that from a luminous watch, as Teller would like us to think, but thousands of times more. The particular genetic hazard is that the gonads of the entire world's population are indeed subjected to irradiation from radioactive fall-out.

Teller mentions 45 kg. of strontium-90 as the total amount produced to date by all test explosions. However, we know that a 10-megaton explosion produces 10 kg. of strontium-90 [79]. So according to Teller only four 10-megaton bombs have been detonated so far. This is obviously not true. (Laurence suggests 75 kg.) In Chapter XI, Teller and Latter go into a detailed explanation about how the quantity of strontium in milk diminishes when it enters the human organism, but they do not give any figures about the strontium intake with vegetable foods. The authors "forget" about the facts, and conceal from the reader the large amounts of strontium-90 in rice and wheat in order to prove the "harmlessness" of the tests.

Many such cases of deliberate distortion of facts could be listed, for Teller's book is full of them. It is obvious that when the issue is one of danger to the lives of people, such methods are not permissible.

Another device is the supposedly objective assessment of the hazard by comparison with existing mortality rates. Even the greatly understated calculations of Teller and Latter indicate tens of thousands of deaths from leukemia due to radioactive contamination. In giving these figures, the authors say that millions of people die annually from natural causes. They compute the percentage increase and assure us that it is small and, therefore, that there is nothing to get worried about. The authors fail to notice that they are contradicting not only generally accepted ethical standards of conduct, but also the penal code of any country. For if they were right, murder would not be punishable as it increases the general mortality by an insignificant, actually indeterminable, per cent.

In society human life is valued strictly individually, and the laws of all countries punish severely every attempt to take the life of a human being. How can the conscience of the community agree that the killing of thousands and millions of people through nuclear testing can be justified by the fact that this number is only a small per cent of the existing death rate?

The ideals that have always inspired and continue to inspire the scientists of the world are the great principles of humanitarianism, the high value of human life, and the selfless struggle to save human lives if they are endangered. No scientist could ever agree to the death of a single person (to say nothing of thousands and millions) for any kind of scientific experiment, and all the more so for experiments that bring us nearer to nuclear warfare, the horrifying consequences of which for humanity are almost impossible to imagine.

However, the defenders of tests try to relieve themselves of responsibility by stating that it is never possible to determine whether a person died from increased radioactivity or from natural causes. As the *New York Herald Tribune* of June 9, 1957 writes, "Dr. Libby also stated that to his knowledge there is no single provable case of any person being injured or seriously affected by any of the slightly extra radiation created in the United States by the tests." How can a serious scientist write things like that? He knows perfectly well that enhanced radioactivity only increases the probability of the disease, and statistical studies in the next few years will undoubtedly show this to be the case in the United States. One can't prove, for instance, just what case of leukemia among the inhabitants of Nagasaki and Hiroshima is due to natural causes and what cases are due to radiation from the atomic bombs dropped by the Americans. But one does know that Hiroshima and Nagasaki have a far higher leukemia incidence than any other Japanese cities [80]. It is precisely here that the incidence of the disease increases

as we approach ground zero, and even Libby doesn't say that this is not connected with the atomic explosions.

Teller concludes chapter XII of his book with the naïve exclamation: "It has been claimed that it is wrong to endanger any human life. Is it not more realistic and in fact more in keeping with the ideals of humanitarianism to strive toward a better life for all mankind?" In his crusade for the continuation of testing, Teller sees "the ideals of humanitarianism" in a cynical disregard for the death of millions from the nuclear tests, he sees "the ideals of humanitarianism" in preparations for a nuclear war that will wipe out centres of civilization and mean death to hundreds of millions of human beings.

Teller, of course, understands perfectly well that no nuclear bomb explosions are needed to work out peaceful ways of utilizing atomic energy so as to create a better life for mankind. His statement that nuclear tests are needed for progress in science is groundless and is invoked for the sole purpose of disorienting the public. The science, in whose development man is interested, can and (we believe) will develop without nuclear explosions that are a hazard to the population of the whole world.

Having failed to convince either the public or even themselves by such flimsy argumentation, the advocates of continued tests throw down their last trump—the "clean" bomb. Test explosions, we are told, are needed to create a new weapon of mass extermination—a clean bomb that is based not on fission but on fusion. This bomb will not yield strontium-90 or cesium-137, the harm will be eliminated, and only benefit will remain—so say the advocates of this new weapon. I would not like to touch on the purely political aspect of this question. To everyone it is clear that the building of a new weapon of mass extermination will not benefit mankind in the least, it will only make for more tension in international relations, it will only increase the probability of a nuclear war that would bring to man incalculable distress. There can be no doubt that such

a war, if it begins, will be pursued with the "dirty" bombs that have been stockpiled by certain countries and that cost much less to make than the "clean" bomb now under development, and all the consequences of radioactive contamination will strike at those that survive the nuclear explosions.

The only thing that I would like to speak about at this point is the relativity in the concept of the "cleanness" of such a bomb. Direct observations conducted on the Soviet research vessel "Vityaz," which was sailing in the area of the Philippine Islands soon after a series of U.S. tests of "clean" bombs, showed a considerable amount of radioactive fall-out, which is clear evidence that a clean bomb only reduces the quantity of radioactive fission products but does not exclude them.

On the other hand, it is a well-known fact that thermonuclear fusion reactions are accompanied by an exceedingly intense neutron radiation. An air burst will lead to the formation of a great deal of radioactive carbon-14. Leipunsky [79] has calculated that the burst of a 10-megaton all-fusion bomb releases 3.3×10^5 grammes of radioactive carbon with a total activity of 1.49×10^6 curies. Only a few such explosions are needed to double the amount of radioactive carbon in the atmosphere. In the form of carbon dioxide, the radiocarbon will be readily absorbed by plants in photosynthesis, and will enter the human body in vegetable foods. The resulting increased irradiation of the organism will not be very great, but since carbon is a constituent of all vitally important structures, it will be incorporated directly into the molecule of desoxyribonucleic acid, and this can increase appreciably the probability of detrimental mutations. Data available in the literature concerning substantial increases in the mutation rate upon the incorporation into DNA of thymine labelled with tritium, as compared with equivalent external irradiation, points to a new hazard for an assessment of which we do not as yet have experimental data.

Another point is that the powerful neutron radiation which attends the bursts of so-called clean bombs will give rise to mutational changes in microorganisms and viruses. This can lead to new and highly virulent forms and, as a next and invariable step, to large-scale epidemics. It is very probable that the severe pandemic of influenza that spread over nearly the whole world in August to October of 1957 was due to the appearance of new forms of influenza virus from the effects of neutron radiation in test explosions.

Teller's book and the views expressed by Libby have not changed anything in the views of scientists that appraise objectively the danger of nuclear explosions. The reasoning of these advocates of continued tests is calculated for a credulous and uninformed reader, and was not accepted by the scientific community of the world. The second Pugwash conference that gathered in Lake Baport (Canada) on March 31, 1958 and was attended by scientists from Australia, Canada, the Chinese People's Republic, France, Great Britain, the Soviet Union and the United States of America, once again pointed out the grave danger to mankind inherent in the testing of nuclear weapons. The conference reached a unanimous decision on the necessity of holding, in the nearest future, a broad and representative conference of the scientists of all countries to discuss problems connected with averting the threat to mankind from the testing and production of nuclear weapons and the atomic arms race.

The Third Pugwash conference was held on September 19, 1958 in Vienna, in the Academy of Sciences. At its final session seventy scientists from 20 countries warmly supported by the broad scientific community of Austria once again appealed to the governments of all countries to put an end to the cold war, to make impossible a nuclear war that would wipe out all the attainments of civilization.

The United Nations Scientific Committee on the Effects of Atomic Radiation, which was set up in 1955 and con-

sists of prominent scientists from fifteen countries, in the course of three years collected, studied and discussed all available scientific material on sources of radiation that affect man, on the growth of radioactivity in our environment, and on the effects of radiation on the living world, primarily on man. In 1958, the Committee completed its work and submitted a report to the General Assembly of the United Nations. The unanimous conclusions that the Committee came to were: that the radioactive contamination from current nuclear explosions subject the entire population of the world to radiation, that the irradiation levels are constantly increasing leading to a new danger (which has not yet been studied sufficiently) to all individuals and to future generations, that the health of the people calls for a ban on the contamination of our environment through explosions of nuclear weapons. The Committee placed special emphasis on the fact that any, even the slightest, increase in the level of radiation is capable of giving rise to lethal genetic and, probably, somatic effects.

Thus, such an authoritative organization as the United Nations Scientific Committee, which includes scientists from Argentina, Australia, Brazil, Canada, Czechoslovakia, Egypt, France, India, Japan, Mexico, Sweden, the Soviet Union, Great Britain, and the United States of America, has taken the same stand on this problem of the danger to mankind of nuclear explosions as have the leading scientific circles of the world.

* * *

We bring to a close this brief description of the misery that awaits people if the testing of nuclear weapons continues, or if the aggressive forces of the capitalist world begin a war with nuclear weapons. The terrible consequences of atomic warfare any place on the globe are becoming clearer to all nations. The struggle of common

people for peace, against the use of nuclear weapons, and for an arms reduction is growing and expanding.

The Soviet Union stands at the head of this struggle for peace, it carries forward a consistent policy for the conclusion of an agreement on the complete cessation of nuclear weapons tests. There can be no doubt that such an agreement between the U.S.S.R., the U.S.A. and Great Britain would be an important step towards putting a ban on nuclear war and towards a reduction of armaments.

The forces of peace are strengthening from year to year. The public is becoming more and more aware of the hopelessness and danger of "power politics," it realizes the incalculable misery that would come of an atomic war.

If this book has helped to understand better the danger that atom and hydrogen explosions bring with them, then it has done its job and has made its contribution to the great cause of peace.

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